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ELEMENTS

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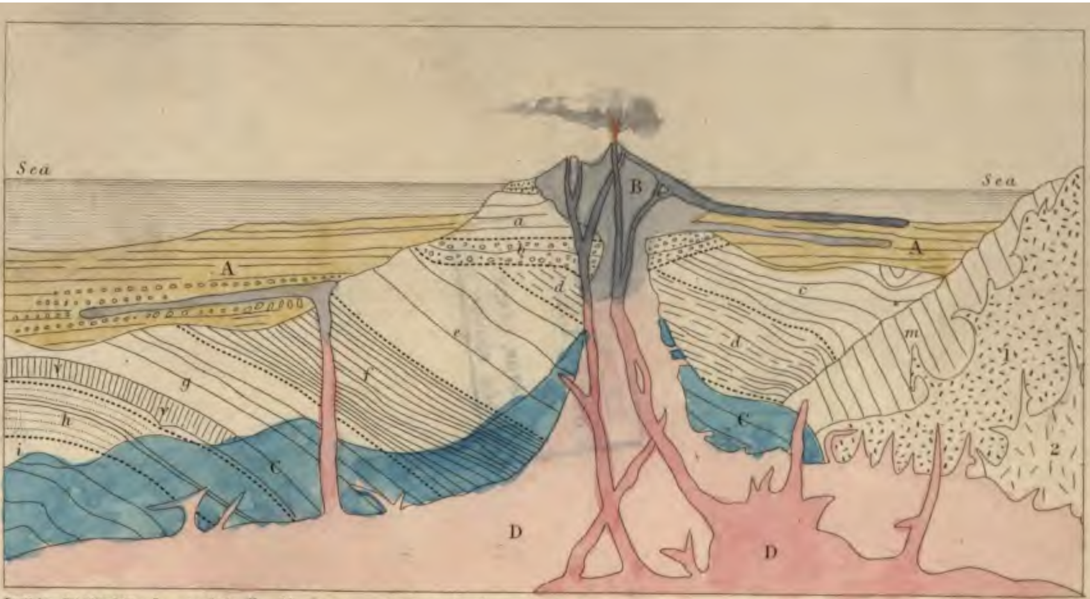

IDEAL SECTION of part of the Earth's crust *explaining the theory of the contemporaneous origin of the four great claſses of rocks.*

A 🟨 Aqueous
B ▨ Volcanic
C 🟦 Metamorphic *(Gneiss, mica-schist &c.)*
D ▭ Plutonic *(Granite &c.)*

All the rocks older than A.B.C.D *are left uncoloured.*

ELEMENTS

OF

GEOLOGY.

BY

CHARLES LYELL, ESQ., F. R. S.

VICE-PRESIDENT OF THE GEOLOGICAL SOCIETY OF LONDON, ETC.;
AUTHOR OF "PRINCIPLES OF GEOLOGY."

"It is a philosophy which never rests,—its law is progress: a point which yesterday was invisible is its goal to-day, and will be its starting post to-morrow."—EDIN. REV., No. 132. p. 83. July, 1837.

IN TWO VOLUMES.

VOL. I.

REPRINTED FROM THE SECOND ENGLISH EDITION.
FROM THE ORIGINAL PLATES AND WOOD CUTS,
UNDER THE DIRECTION OF THE AUTHOR.

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1841.

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TO

WILLIAM HENRY FITTON,

M. D., F. R. S.,

VICE-PRESIDENT OF THE GEOLOGICAL SOCIETY,

ETC.

MY DEAR DR. FITTON,

I HAVE great pleasure in re-dedicating this work to you, as a memorial of an uninterrupted friendship of more than twenty years, during which we have been engaged in the same scientific pursuits. I am also glad to have this opportunity of acknowledging the benefit which my writings have so often derived from your friendly criticism.

I am,
My dear Dr. Fitton,
Yours, very sincerely,
CHARLES LYELL.

LONDON, *July* 10, 1841.

PREFACE.

SINCE the appearance of the First Edition of this Work, I have published a new or Sixth Edition of the "Principles of Geology," omitting altogether that portion contained in previous editions, in which the European tertiary formations were described in some detail. The part thus omitted has, with considerable modifications and corrections, been incorporated in the present edition of the "Elements," so that the two works now occupy very distinct ground; the "Principles" being chiefly confined to those modern changes of the earth and its living inhabitants which are illustrative of Geology, while in the "Elements" I treat of the component materials of the earth's crust considered as the monuments of the successive revolutions through which this globe and its inhabitants have passed in times antecedent to the creation of man.

When I observe that the "Principles of Geology" are *chiefly* confined to the modern changes of the organic and inorganic world, I wish to remind the student that I have prefixed to my systematic account of those changes a series of Essays (comprised in the First Book), in which I have endeavoured to explain those general and theoretical conclusions which the numerous facts now brought to light by geology have led me to adopt, and on which I have not deemed it expedient to enlarge in an elementary work like the present.

I have often been asked which of the two treatises I intend to be read first by one who is willing to study both. In answering this question, I experience much the same difficulty as if asked whether a beginner should take up first a treatise on Chemistry or one on Natural Philosophy, subjects so distinct, and yet so inseparably connected.

Upon the whole, I am inclined to think that those students who are entirely unacquainted with the subject will do well to peruse the "Principles" first, as their curiosity may be thus excited by entering at once on the sketch which has been given of the progress of opinion in geology from the earliest times, and by a discussion of the many questions of general interest to which the examination of the earth's structure gives rise; such as the causes of former changes of climate,—the extinction of species, — the supposed progressive developement of organic life, — the recent origin of man,—the analogy or want of analogy between the igneous and aqueous causes formerly operating and those now in action, and a variety of others which I cannot here enumerate. A perusal of the Second Book of the "Principles" will prepare the reader to comprehend the method of interpreting and classifying geological phenomena, by considering the *recent* effects of inorganic causes, such as rivers, springs, tides, currents, and subterranean heat, whether exhibited in the volcano or earthquake. The concluding part of the same work will give him an insight into the changes which the organic world has undergone in modern times, by explaining the laws which govern the present geographical distribution of the various species of animals and plants, the causes of their multiplication and extinction, and the manner in which their remains become fossil in new deposits.

But, however intimate their connexion, the two treatises are now entirely independent of each other, so that either of them may be taken first in order. I have not repeated in this work a glossary of geological terms which I inserted in the "Principles," but I have defined all technicalities in the places where they are first introduced, and these may easily be referred to by means of the Index.

Among the principal additions made to the present edition of the "Elements," exclusive of the incorporation of numerous topics formerly comprised in the Fourth Book of the "Principles," I may call attention to the following : — In the first volume, facts illustrative of the theory of Denudation, — Parallel Roads and Terraces, — the Boulder formation and erratics, — the former extension of Alpine glaciers, — methods of classifying the tertiary strata. In the second volume, a description of inland chalk cliffs and needles in Normandy, — fossil footsteps, and the discovery of the Labyrinthodon, — erect position of fossil trees in the Coal, — rocks and fossils of the Old Red Sandstone or Devonian formation, — fossils of the Silurian rocks, — Tabular view of fossiliferous strata, — trap-rocks of the Carboniferous period, — granites of Arran.

N. B. The greater part of the woodcuts in this volume are the work of Mr. James Lee, 97. Prince's Square, Kennington. The original drawings in Natural History were done chiefly by Mr. George Sowerby, jun., 10. College Terrace, Cambden New Town.

EXPLANATION

OF

THE FRONTISPIECE.

In this plate an ideal representation is given of a deep section of the earth's crust. The masses A, B, C, and D, represent each of them rocks belonging to the four distinct classes; and the reader will perceive what position they may be supposed to occupy relatively to each other when in the course of simultaneous production. Thus, while the aqueous deposits A, which are expressed by the yellow color, have been accumulating in successive strata at the bottom of the sea, the volcanic cone B has been piled up during a long series of eruptions, and the other igneous rocks colored purple have also ascended from below in a fluid state. Some of these last have been poured forth into the sea, and there mingled with aqueous sediment. On the left side of the plate a sheet of lava is represented reposing upon the yellow strata A, and covered by other parts of the same sedimentary deposit. This lava was the produce of a submarine eruption, and the horizontal layers of fragments above and below it are volcanic tuffs and conglomerates (see Chap. 27). On pursuing downwards either the small dikes or large masses of volcanic rock, we find them pass gradually into plutonic formations (or granites) D, which are colored red, and which underlie all the rest. The different tints of color express two granites, one newer than the other, but belonging, like the upper and lower strata of A, to the same geological period. These plutonic rocks are seen to be in contact with a zone of contemporaneous metamorphic strata, C, colored blue, which they penetrate in numerous veins. The formations, C, originated as fossiliferous strata of the periods, *d*, *e*, *f*, *g*, *h*, *i*, but have acquired a new structure during the accumulation of the strata A ; and belong therefore to the latter period, or A, if we regard them solely in the light of metamorphic rocks; for during the deposition of A they assumed a crystalline form, and were thus regenerated. This section, therefore, may assist the reader in understanding the doctrine that hypogene strata, such as C, may be formed at a considerable depth from the surface, while the incumbent masses *d*, *e*, *f*, *g*, *h*, *i*, still remain fossiliferous, and in great part unaltered.

In that part of the plate which is uncolored a more ancient series of mineral masses are seen, belonging also to the four great divisions of rocks. The strata from *a* to *i* represent as many distinct aqueous formations, which have originated at different periods, and are each distinguished by their peculiar fossils. The mass *v v* is of volcanic origin, and was formed when the strata *g* were in the course of deposition. The strata *m* are metamorphic formations, which assumed a crystalline texture before any of the strata C were so altered as to belong to the hypogene class. The rocks 1, 2, are plutonic of different dates, but more ancient than D, D.

The theoretical views elucidated in this Frontispiece are enlarged upon more fully in Vol. I p. 208., and Vol. II. p 426.

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LATELY PUBLISHED,

Seventh Edition, Revised, 3 vols. 12mo.

PRINCIPLES OF GEOLOGY; or, the Modern Changes of the Earth and its Inhabitants considered, as illustrative of Geology. By Charles Lyell, Esq., F. R. S.

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ON THE DIFFERENT CLASSES OF ROCKS.

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Of what materials is the earth composed, and in what manner are these materials arranged? These are the inquiries with which Geology is occupied, a science which derives its name from the Greek *γῆ*, *ge*, the earth, and *λόγος*, *logos*, a discourse. Such investigations appear, at first sight, to relate exclusively to the mineral kingdom, and to the various rocks, soils, and metals, which occur upon the surface of the earth, or at various depths beneath it. But, in pursuing these researches, we soon find ourselves led on to consider the successive changes which have taken place in the former state of the earth's surface and interior, and the causes which have given rise to these changes; and, what is still more singular and unexpected, we soon become engaged in researches into the history of the animate creation, or of the various tribes of animals and plants which have, at different periods of the past, inhabited the globe.

All are aware that the solid parts of the earth consist of distinct substances, such as clay, chalk, sand, limestone, coal, slate, granite, and the like; but previously to observation it is commonly imagined that all these had remained from the first in the state in which we now see them,—that they were created in their present form, and in their present position. Geologists have come to a different conclusion. They have discovered proofs that the external parts of the earth were not all produced in the beginning of things, in the state in which we now behold them, nor in an instant of time. On the contrary, they have acquired their actual configuration and condition gradually, under a great variety of circumstances, and at successive periods, during each of which distinct races of living beings have flourished on the land and in the waters, the remains of these creatures still lying buried in the crust of the earth.

By the "earth's crust," is meant that small portion of the exterior of our planet which is accessible to human observation, or on which we are enabled to reason by observations made at or near the surface. These reasonings may extend to a depth of several miles, perhaps ten miles; and even then it may be said, that such a thickness is no more than $\frac{1}{400}$ part of the distance from the surface to the centre. The remark is just; but although the dimensions of such a crust are, in truth, insignificant when compared to the entire globe, yet they are vast and of magnificent extent in relation to man, and to the organic beings which people our globe. Referring to this standard of magnitude, the geologist may admire the ample limits of his domain, and admit, at the same time, that not only the exterior of the planet, but the entire earth, is but an atom in the midst of the countless worlds surveyed by the astronomer.

Now the materials of this crust are not thrown together confusedly; but distinct mineral masses, called rocks, are found to occupy definite spaces, and to exhibit a certain order of arrangement. The term *rock* is applied indifferently by geologists to all these substances, whether they be soft or stony, for clay and sand are included in the term, and some have even brought peat under this denomination. Our older writers endeavoured to avoid offering such violence to our language, by speaking of the component materials of the earth as consisting of rocks and *soils*. But there is often so insensible a passage from a soft and incoherent state to that of stone, that geologists of all countries have found it indispensable to have one technical term to include both, and in this sense we find *roche* applied in French, *rocca* in Italian, and *felsart* in German. The beginner, however, must constantly bear in mind, that the term rock by no means implies that the mineral mass is in an indurated or stony condition.

The most natural and convenient mode of classifying the various rocks which compose the earth's crust, is to refer, in the first place, to their origin, and in the second to their relative age. I shall therefore begin by endeavouring briefly to explain to the student how all rocks may be divided into four great classes by reference to their different origin, or, in other words, by reference to the different circumstances and causes by which they have been produced.

The first two divisions, which will at once be understood as natural, are the aqueous and volcanic, or the products of watery and those of igneous action at or near the surface.

Aqueous rocks.—The aqueous rocks, sometimes called the sedimentary, or fossiliferous, cover a larger part of the earth's surface than any others. These rocks are *stratified*, or divided into distinct layers, or strata. The term *stratum* means simply a bed, or any thing spread out or *strewed* over a given surface; and we infer that these strata have been generally spread out by the action of water, from what we daily see taking place near the mouths of rivers, or on the land during temporary inundations. For, whenever a running stream, charged with mud or sand, has its velocity checked, as when it enters a lake or sea, or overflows a plain, the sediment, previously held in suspension by the motion of the water, sinks, by its own gravity, to the bottom. In this manner layers of mud and sand are thrown down one upon another.

If we drain a lake which has been fed by a small stream, we frequently find at the bottom a series of deposits, disposed with considerable regularity, one above the other; the uppermost, perhaps, may be a stratum of peat, next below a more dense and solid variety of the same material; still lower a bed of shell-marl, alternating with peat or sand, and then other beds of marl, divided by layers of clay. Now, if a second pit be sunk through the same continuous lacustrine *formation*, at some distance from the first, nearly the same series of beds is commonly met with, yet with slight variations; some, for example, of the layers of sand, clay, or marl, may be wanting, one or more of them having thinned out and given place to others, or sometimes one of the masses first examined is observed to increase in thickness to the exclusion of other beds.

The term "*formation*," which I have used in the above explanation, expresses in geology any assemblage of rocks which have some character in common, whether of origin, age, or composition. Thus we speak of stratified and unstratified, fresh-water and marine, aqueous and volcanic, ancient and modern, metalliferous and non-metalliferous formations.

In the estuaries of large rivers, such as the Ganges and the Mississippi, we may observe, at low water, phenomena analogous to those of the drained lakes above mentioned, but on a grander scale, and extending over areas several hundred miles in length and breadth. When the periodical inundations subside, the river hollows out a channel to the depth of many yards through horizontal beds of clay and sand, the ends of which are seen exposed in perpendicular cliffs. These beds vary in color, and are occasionally characterized by containing drift-wood or shells. The shells may belong to species peculiar to the river, but are sometimes those of marine testacea, washed into the mouth of the estuary during storms.

The annual floods of the Nile in Egypt are well known, and the fertile deposits of mud which they leave on the plains. This mud is ***stratified***, the thin layer thrown down in one season differing slightly in color from that of a previous year, and being separable from it, as has been observed in excavations at Cairo, and other places. *

When beds of sand, clay, and marl, containing shells and vegetable matter, are found arranged in the same manner in the interior of the earth, we ascribe to them a similar origin; and the more we examine their characters in minute detail, the more exact do we find the resemblance. Thus, for example, at various heights and depths in the earth, and often far from seas, lakes, and rivers, we meet with layers of rounded pebbles composed of different rocks mingled together. They are like the shingle of a sea-beach, or pebbles formed in the beds of torrents and rivers, which are carried down into the ocean, wherever these descend from high grounds bordering a coast. There the gravel is spread out by the waves and currents over a considerable space; but during seasons of drought the torrents and rivers are nearly dry, and have only power to convey fine sand or mud into the sea. Hence, alternate layers of gravel and fine sediment accumulate under water, and such alternations are found by geologists in the interior of every continent.*

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* See Principles of Geology, by the Author, Index, "Nile," "Rivers," &c.

If a stratified arrangement, and the rounded forms of pebbles, are alone sufficient to lead us to the conclusion that certain rocks originated under water, this opinion is further confirmed by the distinct and independent evidence of *fossils*, so abundantly included in the earth's crust. By a *fossil* is meant any body, or the traces of the existence of any body, whether animal or vegetable, which has been buried in the earth by natural causes. Now the remains of animals, especially of aquatic species, are found almost everywhere imbedded in stratified rocks, and sometimes, in the case of limestone, they are in such abundance as to constitute the entire mass of the rock itself. Shells and corals are the most frequent, and with them are often associated the bones and teeth of fishes, fragments of wood, impressions of leaves, and other organic substances. Fossil shells of forms, such as now abound in the sea, are met with far inland, both near the surface and at great depths below it. They occur at all heights above the level of the ocean, having been observed at an elevation of from 8000 to 9000 feet in the Alps and Pyrenees, of more that 13,000 feet in the Andes, and above 16,000 feet in the Himalayas.†

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* See p. 38.

† See Geograph. Journ. vol. iv. p. 64.

These shells belong mostly to marine testacea, but in some places exclusively to forms characteristic of lakes and rivers. Hence it is concluded that some ancient strata were deposited at the bottom of the sea, and others in lakes and estuaries.

When geology was first cultivated, it was a general belief, that these marine shells and other fossils were the effects and proofs of the general deluge; but all who have carefully investigated the phenomena have long rejected this doctrine. A transient flood might be supposed to leave behind it, here and there upon the surface, scattered heaps of mud, sand, and shingle, with shells confusedly intermixed; but the strata containing fossils are not superficial deposits, and do not cover the earth, but constitute the entire mass of mountains. Nor are the fossils mingled without reference to the habits of the creatures, certain genera or species being often found in groups unassociated with any others.

It has been also the favorite notion of some modern writers, who are aware that fossil bodies cannot all be referred to the deluge, that they, and the strata in which they are entombed, may have been deposited in the bed of the ocean during the period which intervened between the creation of man and the deluge. They imagine that the antediluvian bed of the ocean, after having been the receptacle of many stratified deposits, became converted, at the time of the flood, into the lands which we inhabit, and that the ancient continents were at the same time submerged, and became the bed of the present sea. This hypothesis, although preferable to the diluvial theory, since it admits that all fossiliferous strata were successively thrown down from water, is yet wholly inadequate to explain the repeated revolutions which the earth has undergone, and the signs which the existing continents exhibit, in most regions, of having emerged from the ocean at an era far more remote than four thousand years from the present time. Ample proofs of these reiterated revolutions will be given in the sequel, and it will be seen that many distinct sets of sedimentary strata, each several hundreds or thousands of feet thick, are piled one upon the other in the earth's crust, each containing peculiar fossil animals and plants, which are distinguishable with few exceptions from species now living. The mass of some of these strata consists almost entirely of corals, others are made up of shells, others of plants turned into coal, while some are without fossils. In one set of strata the species of fossils are marine, in another, placed immediately above or below, they as clearly prove that the deposit was formed in a brackish estuary or lake. When the student has more fully examined into these appearances, he will become convinced that the time required for the origin of the actual continents must have been far greater than that which is conceded by the theory above alluded to; and likewise that no one universal and sudden conversion of sea into land will account for geological appearances.

We have now pointed out one great class of rocks, which, however they may vary in mineral composition, color, grain, or other characters, external and internal, may nevertheless be grouped together as having a common origin. They have all been formed under water, in the same manner as modern accumulations of sand, mud, shingle, banks of shells, reefs of coral, and the like, and are all characterized by stratification or fossils, or by both.

Volcanic rocks.—The division of rocks which we may next consider are the volcanic, or those which have been produced at or near the surface, whether in ancient or modern times, not by water, but by the action of fire or subterranean heat. These rocks are for the most part unstratified, and are devoid of fossils. They are more partially distributed than aqueous formations, at least in respect to horizontal extension. Among those parts of Europe where they exhibit characters not to be mistaken, I may mention not only Sicily and the country round Naples, but Auvergne, Velay, and Vivarais, now the departments of Puy de Dome, Haute Loire, and Ardêche, towards the centre and south of France, in which are several hundred conical hills, having the forms of modern volcanos, with craters more or less perfect on many of their summits. These cones are composed moreover of lava, sand, and ashes, similar to those of active volcanos. Streams of lava may sometimes be traced from the cones into the adjoining valleys, where they have choked up the ancient channels of rivers with solid rock, in the same manner as some modern flows of lava in Iceland have been known to do, the rivers either flowing beneath or cutting out a narrow passage on one side of the lava. Although none of these French volcanos have been in activity within the period of history or tradition, their forms are often very perfect. Some, however, have been compared to the mere skeletons of volcanos, the rains and torrents having washed their sides, and removed all the loose sand and scoriæ, leaving only the harder and more solid materials. By this erosion, and by earthquakes, their internal structure has occasionally been laid open to view, in fissures and ravines; and we then behold not only many successive beds and masses of porous lava, sand, and scoriæ, but also perpendicular walls, or *dikes*, as they are called, of volcanic rock, butting through the other materials. Such dikes are also observed in the structure of Vesuvius, Etna, and other active volcanos. They have been formed by the pouring of melted matter, whether from above or below, into open fissures, and they commonly traverse deposits of *volcanic tuff*, a substance produced by the showering down from the air, or incumbent waters, of sand and cinders, first shot up from the interior of the earth by the explosions of volcanic gases.

Besides the parts of France, above alluded to, there are other countries, as the north of Spain, the south of Sicily, the Tuscan territory of Italy, the lower Rhenish provinces, and Hungary, where spent volcanos may be seen, still preserving in many cases a conical form, and having craters and often lava-streams connected with them.

There are also other rocks in England, Scotland, Ireland, and almost every country in Europe, which we infer to be of igneous origin, although they do not form hills with cones and craters. Thus, for example, we feel assured that the rock of Staffa, and that of the Giants' Causeway, called basalt, is volcanic, because it agrees in its columnar structure and mineral composition with streams of lava which we know to have flowed from the craters of volcanos. We find also similar basaltic and other igneous rocks associated with beds of *tuff* in various parts of the British Isles, and forming *dikes*, such as have been spoken of; and some of the strata through which these dikes cut are occasionally altered at the point of contact, as if they had been exposed to the intense heat of melted matter.

The absence of cones and craters, and long narrow streams of superficial lava, in England and many other countries, is principally to be attributed to the eruptions having been submarine, just as a considerable proportion of volcanos in our own times burst out beneath the sea. But this question must be enlarged upon more fully in the chapters on Igneous Rocks, in which it will also be shown, that as different sedimentary formations, containing each their characteristic fossils, have been deposited at successive periods, so also volcanic sand and scoriæ have been thrown out, and lavas have flowed over the land or bed of the sea, at many different epochs, or have been injected into fissures; so that the igneous as well as the aqueous rocks may be classed as a chronological series of monuments, throwing light on a succession of events in the history of the earth.

Plutonic rocks (Granite, &c.). — We have now pointed out the existence of two distinct orders of mineral masses, the aqueous and the volcanic: but if we examine a large portion of a continent, especially if it contain within it a lofty mountain range, we rarely fail to discover two other classes of rocks, very distinct from either of those above alluded to, and which we can neither assimilate to deposits such as are now accumulated in lakes or seas, nor to those generated by ordinary volcanic action. The members of both these divisions of rocks agree in being highly crystalline and destitute of organic remains. The rocks of one division have been called plutonic, comprehending all the granites and certain porphyries, which are nearly allied in some of their characters to volcanic formations. The members of the other class are stratified and often slaty, and have been called by some the *crystalline schists*, in which group are included gneiss, micaceous-schist (or mica-slate), hornblende-schist, statuary marble, the finer kinds of roofing slate, and other rocks afterwards to be described.

As it is admitted that nothing strictly analogous to these crystalline productions can now be seen in the progress of formation on the earth's surface, it will naturally be asked, on what data we can find a place for them in a system of classification founded on the origin of rocks. I cannot, in reply to this question, pretend to give the student, in a few words, an intelligible account of the long chain of facts and reasonings by which geologists have been led to infer the analogy of the rocks in question to others now in progress at the surface. The result, however, may be briefly stated. All the various kinds of granite, which constitute the plutonic family, are supposed to be of igneous origin, but to have been formed under enormous pressure, and at considerable depths in the earth. Like the lava of volcanos, they have been melted, and have afterwards cooled and crystallized, but with extreme slowness, and under conditions very different from those of bodies cooling in the open air. Hence they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, or beneath seas of inconsiderable depth. They differ also by the absence of pores or cellular cavities, to which the expansion of the entangled gases gives rise in ordinary lava.

Although granite has often pierced through other strata, it has rarely, if ever, been observed to rest upon them, as if it had overflowed. But as this is continually the case with the volcanic rocks, they have been styled from this peculiarity, "overlying," by Dr. MacCulloch; and Mr. Necker has proposed the term "underlying," for the granites, to designate the opposite mode in which they almost invariably present themselves.

Metamorphic, or stratified crystalline rocks. — The fourth and last great division of rocks are the crystalline strata and slates, or schists, called gneiss, mica-schist, clay-slate, chlorite-schist, marble, and the like, the origin of which is more doubtful than that of the other three classes. They contain no pebbles or sand or scoriæ, or angular pieces of imbedded stone, and no traces of organic bodies, and they are often as crystalline as granite, yet are divided into beds, corresponding in form and arrangement to those of sedimentary formations, and are therefore said to be stratified. The beds sometimes consist of an alternation of substances varying in color, composition, and thickness, precisely as we see in stratified fossiliferous deposits. According to the Huttonian theory, which I adopt as most probable, and which will be afterwards more fully explained, the materials of these strata were originally deposited from water in the usual form of sediment, but they were subsequently so altered by subterranean heat, as to assume a new texture. It is demonstrable, in some cases at least, that such a complete conversion has actually taken place, fossiliferous strata having exchanged an earthy for a highly crystalline texture for a distance of a quarter of a mile from their contact with granite. In some cases, dark limestones, replete with shells and corals, have been turned into white statuary marble, and hard clays into slates called mica-schist and hornblende-schist, all signs of organic bodies having been obliterated.

Although we are in a great degree ignorant of the precise nature of the influence exerted in these cases, yet it evidently bears some analogy to that which volcanic heat and gases are known to produce; and the action may be conveniently called plutonic, because it appears to have been developed in those regions where plutonic rocks are generated, and under similar circumstances of pressure and depth in the earth. Whether electricity or any other causes have coöperated with heat, may be matter of speculation, but the plutonic influence has sometimes pervaded entire mountain masses of strata.

In accordance with the hypothesis above alluded to, I proposed, in the first edition of the Principles of Geology (1833), the term "Metamorphic," for the altered strata, a term derived from μετά (meta), *trans*, and μορφή (morphe), *forma*.

Hence there are four great classes of rocks considered in reference to their origin,—the aqueous, the volcanic, the plutonic, and the metamorphic. In the course of this work it will be shown, that portions of each of these four distinct classes have originated at many successive periods. They have all been produced contemporaneously, and may even now be in the progress of formation. It is not true, as was formerly supposed, that all granite, together with the crystalline or metamorphic strata, were first formed, and therefore entitled to be called "primitive," and that the aqueous and volcanic rocks were afterwards superimposed, and should, therefore, rank as secondary in the order of time. This idea was adopted in the infancy of the science, when all formations, whether stratified or unstratified, earthy or crystalline, with or without fossils, were alike regarded as of aqueous origin. At that period it was naturally argued, that the foundation must be older than the superstructure ; but it was afterwards discovered, that this opinion was by no means in every instance a legitimate deduction from facts ; for the inferior parts of the earth's crust have often been modified, and even entirely changed by the influence of volcanic and other subterranean causes, while superimposed formations have not been in the slightest degree altered. In other words, the destroying and renovating processes have given birth to new rocks below, while those above, whether crystalline or fossiliferous, have remained in their ancient condition. Even in cities, such as Venice and Amsterdam, it cannot be laid down as universally true, that the upper parts of each edifice, whether of brick or marble, are more modern than the foundations on which they rest, for these often consist of wooden piles, which may have rotted and been replaced one after the other, without the least injury to the buildings above ; meanwhile, these may have required scarcely any repair, and may have been constantly inhabited. So is it with the habitable surface of our globe, and with large masses of rock immediately below it: they may continue the same for ages, while subjacent materials, at a still greater depth, are passing from a solid to a fluid state, acquiring a new texture, and afterwards becoming re-consolidated.

As all the crystalline rocks may, in some respects, be viewed as belonging to one great family, whether they be stratified or unstratified, plutonic or metamorphic, it will often be convenient to speak of them by one common name. It being now ascertained, as above stated, that they are of very different ages, sometimes newer than the strata called secondary, the term primary, which was formerly used for the whole, must be abandoned, as it would imply a manifest contradiction. It is indispensable, therefore, to find a new name, one which must not be of chronological import, and must express, on the one hand, some peculiarity equally attributable to granite and gneiss (to the plutonic as well as the *altered* rocks), and, on the other, must have reference to characters in which those rocks differ, both from the volcanic and from the *unaltered* sedimentary strata. I proposed in the Principles of Geology (first edition, vol. iii.), the term "hypogene" for this purpose, derived from *ὑπό*, *under*, and *γίνομαι*, *to be born*; a word implying the theory that granite, gneiss, and the other crystalline formations are alike *nether-formed* rocks, or rocks which have not assumed their present form and structure at the surface.

From what has now been said, the reader will understand that each of the four great classes of rocks may be studied under two distinct points of view: first, they may be studied simply as mineral masses, deriving their origin from particular causes, and having a certain composition, form, and position in the earth's crust, or other characters both positive and negative, such as the presence or absence of organic remains. In the second place, the rocks of each class may be viewed as a grand chronological series of monuments, attesting a succession of events in the former history of the globe and its living inhabitants.

I shall accordingly proceed to treat of each family of rocks; first, in reference to those characters which are not chronological, and then in particular relation to the several periods when they were formed.

CHAPTER II.

AQUEOUS ROCKS — THEIR COMPOSITION AND FORMS OF STRATIFICATION.

Mineral composition of strata — Arenaceous rocks — Argillaceous — Calcareous — Gypsum — Forms of stratification — Original horizontality — Thinning out—Diagonal arrangement — Ripple mark.

First, then, in pursuance of the arrangement explained in the last chapter, we have to examine the aqueous or sedimentary rocks, which are for the most part distinctly stratified, and contain fossils. We are first to consider them with reference to their mineral composition, external appearance, position, mode of origin, and other characters which belong to them as aqueous formations, independently of their age, or the various geological periods when they may have originated.

I have already given an outline of the data which led to the belief that the stratified and fossiliferous rocks were originally deposited under water; but, before entering into a more detailed investigation, it will be desirable to say something of the ordinary materials of which such strata are composed. These may be said to belong principally to three divisions, the arenaceous, the argillaceous, and the calcareous, which are formed respectively of sand, clay, and carbonate of lime. Ofthese, the arenaceous, or sandy masses, are chiefly made up of siliceous or flinty grains; the argillaceous, or clayey, of a mixture of siliceous matter, with a certain proportion, about a fourth in weight, of aluminous earth; and lastly, the calcareous rocks or limestones consist of carbonic acid and lime.

Arenaceous or siliceous rocks.—To speak first of the sandy division: beds of loose sand are frequently met with, of which the grains consist entirely of silex, which term comprehends all purely siliceous minerals, as quartz and common flint. Quartz is silex in its purest form; flint usually contains some admixture of alumine and oxide of iron. The siliceous grains in sand are usually rounded, as if by the action of running water. Sandstone is an aggregate of such grains, which often cohere together without any visible cement, but more commonly are bound together by a slight quantity of siliceous or calcareous matter, or by iron or clay.

Pure siliceous rocks may be known by not effervescing when a drop of vinegar or other acid is applied to them, or by the grains not being readily scratched or broken by ordinary pressure. In nature there is every intermediate gradation, from perfectly loose sand, to the hardest sandstone. In *micaceous sandstones* mica is very abundant; and the thin silvery plates into which that mineral divides, are often arranged in layers parallel to the planes of stratification, giving a slaty or laminated texture to the rock.

When sandstone is coarse-grained, it is usually called *grit*. If the grains are rounded, and large enough to be called pebbles, it becomes a *conglomerate*, or *pudding-stone*, which may consist of pieces of one or of many different kinds of rock. A conglomerate, therefore, is simply gravel bound together by a cement.

Argillaceous rocks. — Clay, strictly speaking, is a mixture of silex or flint with a large proportion, usually about one fourth, of the substance called alumine, or argil; but, in common language, any earth which possesses sufficient ductility, when kneaded up with water, to be fashioned like paste by the hand, or by the potter's lathe, is called a *clay;* and such clays vary greatly in their composition, and are, in general, nothing more than mud derived from the decomposition or wearing down of various rocks. The purest clay found in nature is porcelain clay, or kaolin, which results from the decomposition of a rock composed of felspar and quartz, and it is almost always mixed with quartz.* *Shale* has also the property, like clay, of becoming plastic in water: it is a more solid form of clay, having been probably condensed by pressure. It usually divides into irregular laminæ.

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* The kaolin of China consists of 71·15 parts of silex,

One general character of all argillaceous rocks is to give out a peculiar or earthy odor when breathed upon, which is a test of the presence of alumine, although it does not belong to pure alumine, but, apparently, to the combination of that substance with oxide of iron.*

Calcareous rocks. — This division comprehends those rocks which, like chalk, are composed chiefly of lime and carbonic acid. Shells and corals are also formed of the same elements, with the addition of animal matter. To obtain pure lime it is necessary to calcine these calcareous substances, that is to say, to expose them to heat of sufficient intensity to drive off the carbonic acid, and other volatile matter, without vitrifying or melting the lime itself. White chalk is often pure carbonate of lime; and this rock, although usually in a soft and earthy state, is sometimes sufficiently solid to be used for building, and even passes into a *com-*

15·86 of alumine, 1·92 of lime, and 6·73 of water (W. Phillips, Mineralogy, p. 33.); but other porcelain clays differ materially, that of Cornwall being composed, according to Boase, of nearly equal parts of silica and alumine, with 1 per cent. of magnesia. (Phil. Mag. vol. x. 1837.)

* See W. Phillips's Mineralogy, "Alumine."

pact stone, or a stone of which the separate parts are so minute as not to be distinguishable from each other by the naked eye.

Many limestones are made up entirely of minute fragments of shells and coral, or of calcareous sand cemented together. These last might be called "calcareous sandstones"; but that term is more properly applied to a rock in which the grains are partly calcareous and partly siliceous, or to quartzose sandstones, having a cement of carbonate of lime.

The variety of limestone called "oolite" is composed of numerous small egg-like grains, resembling the roe of a fish, each of which has usually a small fragment of sand as a nucleus, around which concentric layers of calcareous matter have accumulated.

Any limestone which is sufficiently hard to take a fine polish is called *marble*. Many of these are fossiliferous; but statuary marble, which is also called saccharine limestone, as having a texture resembling that of loaf-sugar, is devoid of fossils, and is in many cases a member of the metamorphic series.

Siliceous limestone is an intimate mixture of carbonate of lime and flint, and is harder in proportion as the flinty matter predominates.

The presence of carbonate of lime in a rock may be ascertained by applying to the surface a small drop of diluted sulphuric, nitric, or muriatic acids, or vinegar; for the lime, having a stronger chemical affinity for any one of these acids than for the carbonic, unites itself immediately with them to form new compounds, thereby becoming a sulphate, nitrate, or muriate of lime. The carbonic acid, when thus liberated from its union with the lime, escapes in a gaseous form, and froths up or effervesces as it makes its way in small bubbles through the drop of liquid. This effervescence is brisk or feeble in proportion as the limestone is pure or impure, or, in other words, according to the quantity of foreign matter mixed with the carbonate of lime. Without the aid of this test, the most experienced eye cannot always detect the presence of lime in rocks.

The abovementioned three classes of rocks, the arenaceous, argillaceous, and calcareous, pass continually into each other, and rarely occur in a perfectly separate and pure form. Thus it is an exception to the general rule to meet with a limestone as pure as ordinary white chalk, or with clay as aluminous as that used in Cornwall for porcelain, or with sand so entirely composed of siliceous grains as the white sand of Alum Bay in the Isle of Wight, or sandstone so pure as the grit of Fontainebleau, used for pavement in France. More commonly we find sand and clay, or clay and marl, intermixed in the same mass. When the sand and clay are each in considerable quantity, the mixture is called *loam*. If there is much calcareous matter in clay it is called *marl;* but this term has unfortunately been used so vaguely, as often to be very ambiguous. It has been applied to substances in which there is no lime; as, to that red loam usually called red marl in certain parts of England. Agriculturists were in the habit of calling any soil a marl, which, like true marl, fell to pieces readily on exposure to the air. Hence arose the confusion of using this name for soils which, consisting of loam, were easily worked by the plough, though devoid of lime.

Marl slate bears the same relation to marl which shale bears to clay, being a calcareous shale. It is very abundant in some countries, as in the Swiss Alps. Argillaceous or marly limestone is also of common occurrence.

There are few other kinds of rock which enter so largely into the composition of sedimentary strata as to make it necessary to dwell here on their characters. I may, however, mention two others, — magnesian limestone or dolomite, and gypsum. *Magnesian limestone* is composed of carbonate of lime and carbonate of magnesia: the proportion of the latter amounting in some cases to nearly one half. It effervesces much more slowly and feebly with acids than common limestone. In England this rock is generally of a yellowish color; but it varies greatly in mineralogical character, passing from an earthy state to a white compact stone of great hardness. *Dolomite*, so common in many parts of Germany and France, is also a variety of magnesian limestone, usually of a granular texture.

Gypsum.—Gypsum is a rock composed of sulphuric acid, lime, and water. It is usually a soft, whitish-yellow rock, with a texture resembling that of loaf-sugar, but sometimes it is entirely composed of lenticular crystals. It is insoluble in acids, and does not effervesce like chalk and dolomite, because it does not contain carbonic acid gas, or fixed air, the lime being already combined with sulphuric acid, for which it has a stronger affinity than for any other. Anhydrous gypsum is a rare variety, into which water does not enter as a component part. Gypseous marl is a mixture of gypsum and marl.

Forms of stratification.—A series of strata sometimes consists of one of the above rocks, sometimes of two or more in alternating beds. Thus, in the coal districts of England, for example, we often pass through several beds of sandstone, some of finer, others of coarser grain, some white, others of a dark color, and below these, layers of shale and sandstone or beds of shale, divisible into leaf-like laminæ, and containing beautiful impressions of plants. Then again we meet with beds of pure and impure coal, alternating with shales, and underneath the whole, perhaps, are calcareous strata, or beds of limestone, filled with corals and marine shells, each bed distinguishable from another by certain fossils, or by the abundance of particular species of shells or zoophytes.

This alternation of different kinds of rock produces the most distinct stratification; and we often find beds of limestone and marl, conglomerate and sandstone, sand and clay, recurring again and again, in nearly regular order, throughout a series of many hundred strata. The causes which may produce these phenomena are various, and have been fully discussed in my treatise on the modern changes of the earth's surface.* It is there seen that rivers flowing into lakes and seas are charged with sediment, varying in quantity, composition, color, and grain according to the seasons; the waters are sometimes flooded and rapid, at other periods low and feeble; different tributaries, also, draining peculiar countries and soils, and therefore charged with peculiar sediment, are swollen at distinct periods. It was also shown that the waves of the sea and currents undermine the cliffs during wintry storms, and sweep away the materials into the deep, after which a season of tranquillity succeeds, when nothing but the finest mud is spread by the movements of the ocean over the same submarine area.

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* Consult Index to Prin. of Geol. "Stratification," "Currents," "Deltas," "Water," &c.

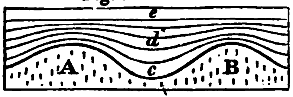
It is not the object of the present work to give a description of these operations, repeated as they are, year after year, and century after century; but I may suggest an explanation of the manner in which some micaceous sandstones have originated, those in which we see innumerable thin layers of mica dividing layers of fine quartzose sand. I observed the same arrangement of materials in recent mud deposited in the estuary of La Roche St. Bernard in Brittany, at the mouth of the Loire. The surrounding rocks are of gneiss, which, by its waste, supplies the mud: when this dries at low water, it is found to consist of brown laminated clay, divided by thin seams of mica. The separation of the mica in this case, or in that of micaceous sandstones, may be thus understood. If we take a handful of quartzose sand, mixed with mica, and throw it into a clear running stream, we see the materials immediately sorted by the water, the grains of quartz falling almost directly to the bottom, while the plates of mica take a much longer time to reach the bottom, and are carried further down the stream. At the first instant the water is turbid, but immediately after the flat surfaces of the plates of mica are seen alone reflecting a silvery light, and they descend slowly, to form a distinct micaceous lamina. The mica is the heavier mineral of the two; but it remains longer suspended, owing to its great extent of surface. It is easy, therefore, to conceive how the intermittent action of waves, currents, and tides, may sort the sediment brought down from the waste of a granitic country, and throw down the mica, layer after layer, separately from the mud or sand.

Original horizontality. — It has generally been said that the upper and under surfaces of strata, or the planes of stratification, as they are termed, are parallel. Although this is not strictly true, they make an approach to parallelism, for the same reason that sediment is usually deposited at first in nearly horizontal layers. The reason of this arrangement can by no means be attributed to an original evenness or horizontality in the bed of the sea; for it is ascertained that in those places where no matter has been recently deposited, the bottom of the ocean is often as uneven as that of the dry land, having in like manner its hills, valleys, and ravines. Yet if the sea should sink, or the water be removed near the mouth of a large river where a delta has been forming, we should see extensive plains of mud and sand laid dry, which, to the eye, would appear perfectly level, although, in reality, they would slope gently from the land towards the sea.

This tendency in newly-formed strata to assume a horizontal position arises principally from the motion of the water, which forces along particles of sand or mud at the bottom, and causes them to settle in hollows or depressions, where they are less exposed to the force of a current than when they are resting on elevated points. The velocity of the current and the motion of the superficial waves diminish from the surface downwards, and are least in those depressions where the water is deepest.

A good illustration of the principle here alluded to may be sometimes seen in the neighbourhood of a volcano, when a section, whether natural or artificial, has laid open to view a succession of various-colored layers of sand and ashes, which have fallen in showers upon uneven ground. Thus let A, B (Fig. 1.) be two ridges, with an intervening valley. These original inequalities of the surface have been gradually effaced by beds of sand and ashes *c*, *d*, *e*, the surface at *e* being quite level. It will be seen that although the materials of the first layers have accommodated themselves in a great degree to the shape of the ground A B, yet each bed is thickest at the bottom. At first a great many particles would be carried by their own gravity down the steep sides of A and B, and others would afterwards be blown by the wind as they fell off the ridges, and would settle in the hollow, which would thus be-

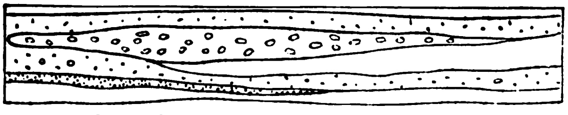
Fig. 1.



come more and more effaced as the strata accumulated from *c* to *e*. This levelling operation may perhaps be rendered more clear to the student by supposing a number of parallel trenches to be dug in a plain of moving sand, like the African desert, in which case the wind would soon cause all signs of these trenches to disappear, and the surface would be as uniform as before. Now, water in motion can exert this levelling power on similar materials more easily than air, for almost all stones lose in water more than a third of the weight which they have in air, the specific gravity of rocks being in general as 2½ when compared to that of water, which is estimated at 1. But the buoyancy of sand or mud would be still greater in the sea, as the density of salt water exceeds that of fresh.

Yet, however uniform and horizontal may be the surface of new deposits in general, there are still many disturbing causes, such as eddies in the water, and currents moving first in one and then in another direction, which frequently cause irregularities. We may sometimes follow a bed of limestone, shale, or sandstone, for a distance of many hundred yards continuously; but we generally find at length that each individual stratum thins

Fig. 2.

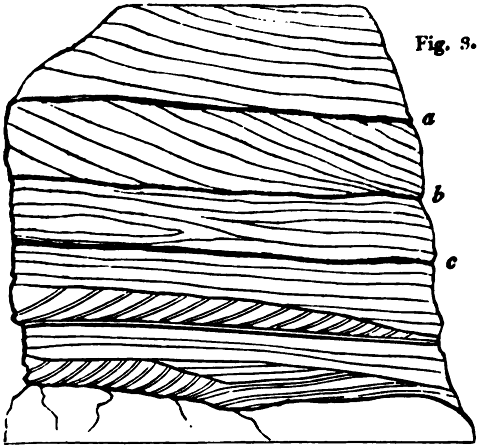


Section of strata of sandstone, grit, and conglomerate.

out, and allows the beds which were previously above and below it to meet. If the materials are coarse, as in grits and conglomerates, the same beds can rarely be traced many yards without varying in size, and often coming to an end abruptly. (See Fig. 2.)

Diagonal stratification. — There is also another phenomenon of frequent occurrence. We find a series of larger strata, each of which is composed of a number of minor layers placed obliquely to the general planes of stratification. To this diagonal arrangement the name of " false stratification " has been given. Thus in the annexed section (Fig. 3.) we see seven or eight large beds of loose sand, yellow and brown, and the lines *a*

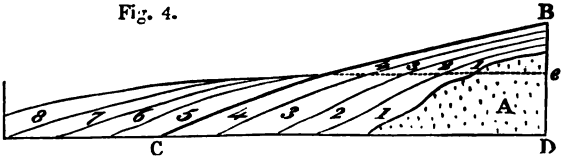
Fig. 3.



Section of sand at Sandy Hill, near Biggleswade, Bedfordshire. Height twenty feet. (Green-sand formation.)

b, *c*, mark some of the principal planes of stratification, which are nearly horizontal. But the greater part of the subordinate laminæ do not conform to these planes, but have often a steep slope, the inclination being sometimes towards opposite points of the compass. When the sand is loose and incoherent, as in the case here represented, the deviation from parallelism of the slanting laminæ cannot possibly be accounted for by any re-arrangement of the particles acquired during the consolidation of the rock. In what manner then can such irregularities be due to original deposition? We must suppose that at the bottom of the sea, as well as in the beds of rivers, the motion of waves, currents, and eddies often cause mud, sand, and gravel to be thrown down in heaps on particular spots, instead of being spread out uniformly over a wide area. Sometimes, when banks are thus formed, currents may cut passages through them, just as a river forms its bed. Suppose the bank A (Fig. 4.) to be thus formed with a steep sloping side, and the

Fig. 4.



water being in a tranquil state, the layer of sediment No. 1. is thrown down upon it, conforming nearly to its surface. Afterwards the other layers, 2, 3, 4, may be deposited in succession, so that the bank B C D is formed. If the current then increases in velocity, it may cut away the upper portion of this mass down to the dotted line *e* (Fig. 4.), and deposit the materials thus removed further on, so as to form the layers 5, 6, 7, 8. We have now the bank B C D E (Fig. 5.), of which the surface is almost level, and on which the nearly horizontal layers, 9, 10, 11, may then accumulate. It was shown in Fig. 4. that the diagonal layers of successive strata may sometimes have an opposite slope. This is well seen in some cliffs of loose sand on the Suffolk coast. A portion of one of these is represented in Fig. 6., where the layers, of which there are about six in the thickness of an inch, are composed of quartzose grains.

Fig. 5.

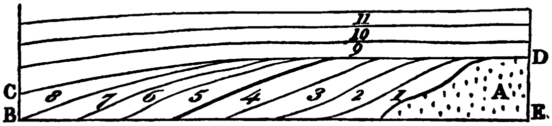
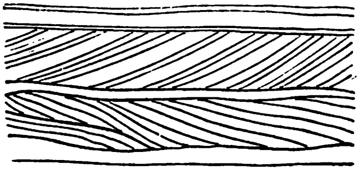


Fig. 6.

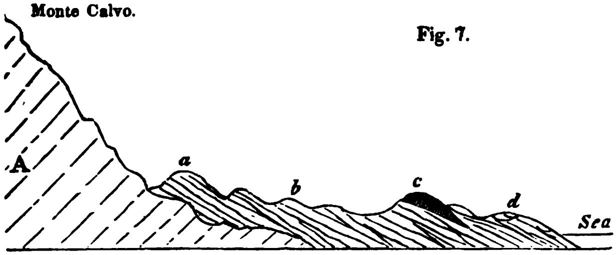


Cliff between Mismer and Dunwich.

This arrangement may have been due to the altered direction of the tides and currents in the same place.

The description above given of the slanting position of the minor layers constituting a single stratum is in certain cases applicable on a much grander scale to masses several hundred feet thick, and many miles in extent. A fine sample may be seen at the base of the Maritime Alps near Nice. The mountains here terminate abruptly in the sea, so that a depth of many hundred fathoms is often found within a stone's throw of the beach, and sometimes a depth of 3000 feet within half a mile. But at certain points, strata of sand marle, or conglomerate, intervene between the shore and the mountains, as in the annexed Fig. (7.), where a vast succession of slanting beds of gravel and sand may be traced

Fig. 7.



Section from Monte Calvo to the sea by the valley of Magnan, near Nice.

A. Dolomite and sandstone. (Green-sand formation ?)
a, b, d. Beds of gravel and sand.
c. Fine marl and sand of St. Madeleine, with marine shells.

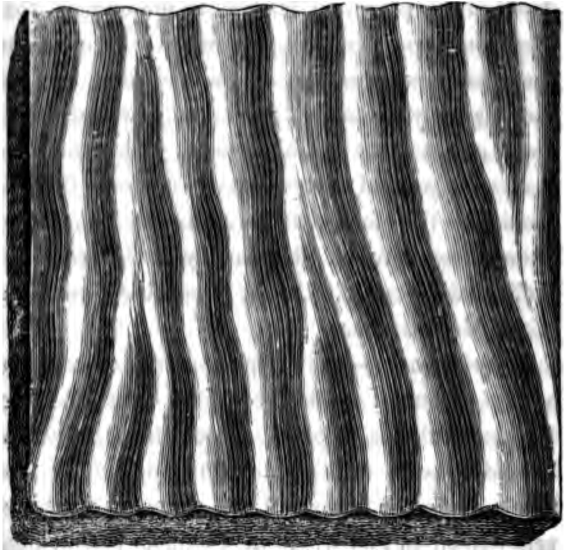
from the sea to Monte Calvo, a distance of no less than nine miles in a straight line. The dip of these beds is remarkably uniform, being always southward or towards the Mediterranean, at an angle of about 25°. They are exposed to view in nearly vertical precipices, varying from 200 to 600 feet in height, which bound the valley through which the river Magnan flows. Although in a general view, the strata appear to be parallel and uniform, they are nevertheless found, when examined closely, to be wedge-shaped, and to thin out when followed for a few hundred feet or yards, so that we may suppose them to have been thrown down originally upon the side of a steep bank, where a river or alpine torrent discharged itself into a deep and tranquil sea, and formed a delta, which advanced gradually from the base of Monte Calvo to a distance of 9 miles from the original shore. If subsequently this part of the Alps and bed of the sea were raised 700 feet, the coast would acquire its present configuration, the delta would emerge, and a deep channel might then be cut through it by a river.

It is well known that the torrents and streams, which now descend from the alpine declivities to the shore, bring down annually, when the snow melts, vast quantities of shingle and sand, and then, as they subside, fine mud, while in summer they are nearly or entirely dry; so that it may be safely assumed, that deposits like those of the valley of Magnan, consisting of coarse gravel alternating with fine sediment, are still in progress at many points, as for instance, at the mouth of the Var. They must advance upon the Mediterranean in the form of great shoals terminating in a steep talus; such being the original mode of accumulation of all coarse materials conveyed into deep water, especially where they are composed, in great part, of pebbles, which cannot be transported to indefinite distances by currents of moderate velocity. By inattention to facts and inferences of this kind, a very exaggerated estimate has sometimes been made of the supposed depth of the ancient ocean. There can be no doubt, for example, that the strata *a*, Fig. 7., or those nearest to Monte Calvo, are older than those indicated by *b*, and these again were formed before *c;* but the vertical depth of gravel and sand in any one place cannot be proved to amount even to 1000 feet, although it may perhaps be much greater, yet probably never exceeding at any point 3000 or 4000 feet. But were we to assume that all the strata were once horizontal, and that their present dip or inclination was due to subsequent movements, we should then be forced to conclude, that a sea 9 miles deep had been filled up with alternate layers of mud and pebbles thrown down one upon another.

In the locality now under consideration, situated a few miles to the west of Nice, there are many geological data which there is not room to detail in this place, all leading to the opinion, that when the deposit of the Magnan was formed, the shape and outline of the alpine declivities and the shore greatly resembled what we now behold at many points in the neighbourhood. That the beds *a*, *b*, *c*, *d*, are of comparatively modern date is proved by this fact, that in seams of loamy marl intervening between the pebbly beds are fossil shells, half of which belong to species now living in the Mediterranean.

Ripple mark. — The ripple mark, so common on the surface of sandstones of all ages (see Fig. 8.), and which is so often seen on the sea-shore at low tide, seems to originate in the drifting of materials along the bottom of the water, in a manner very similar to that which may explain the inclined layers above described. This ripple is not entirely confined to the beach between high and low water mark, but is also produced on sands which are constantly covered by water. Similar undulating ridges and furrows may also be sometimes seen on the surface of drift snow and blown sand. The following is the manner in which I once observed the motion of the air to produce this effect on a large extent of level beach, exposed at low tide near Calais. Clouds of fine white sand were blown from the neighbouring dunes, so as to cover the shore, and whiten a dark level surface of sandy

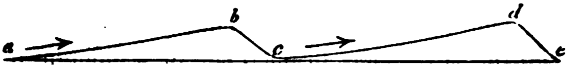
Fig. 8.



Slab of ripple-marked (new red) sandstone from Cheshire.

mud, and this fresh covering of sand was beautifully rippled. On levelling all the small ridges and furrows of this ripple over an area several yards square, I saw them perfectly restored in about ten minutes, the general direction of the ridges being always at right angles to that of the wind. The restoration began by the appearance here and there of small detached heaps of sand, which soon lengthened and joined together, so as to form long sinuous ridges with intervening furrows. Each ridge had one side slightly inclined,

Fig. 9.



and the other steep; the lee-side being always steep, as *b*, *c*, — *d*, *e*; the windward-side a gentle slope, as *a*, *b*, — *c*, *d*, Fig. 9. When a gust of wind blew with sufficient force to drive along a cloud of sand, all the ridges were seen to be in motion at once, each encroaching on the furrow before it, and, in the course of a few minutes, filling the place which the furrows had occupied. The mode of advance was by the continual drifting of grains of sand up the slope *a b* and *c d*, many of which grains, when they arrived at *b* and *d*, fell over the scarps *b c* and *d e*, and were under shelter from the wind; so that they remained stationary, resting, according to their shape and momentum, on different parts of the descent, and a few only rolling to the bottom. In this manner each ridge was distinctly seen to move slowly on as often as the force of the wind augmented. Occasionally part of a ridge, advancing more rapidly than the rest, overtook the ridge immediately before it, and became confounded with it, thus causing those bifurcations and branches which are so common, and two of which are seen in the slab, Fig. 8. We may observe this configuration in sandstones of all ages, and in them also, as now on the sea-coast, we may often detect two systems of ripples interfering with each other; one more ancient and half effaced, and a newer one, in which the grooves and ridges are more distinct, and in a different direction. This crossing of two sets of ripples arises from a change of wind, and the new direction in which the waves are thrown on the shore.

CHAPTER III.

ARRANGEMENT OF FOSSILS IN STRATA,—FRESHWATER AND MARINE.

Successive deposition indicated by fossils — Limestones formed of corals and shells — Proofs of gradual increase of strata derived from fossils — Serpula attached to spatangus — Wood bored by teredina — Tripoli and semi-opal formed of infusoria — Chalk derived principally from organic bodies — Distinction of freshwater from marine formations — Genera of freshwater and land shells — Rules for recognising marine testacea — Gyrogonite and chara — Freshwater fishes — Alternation of marine and freshwater deposits — Lym-Fiord.

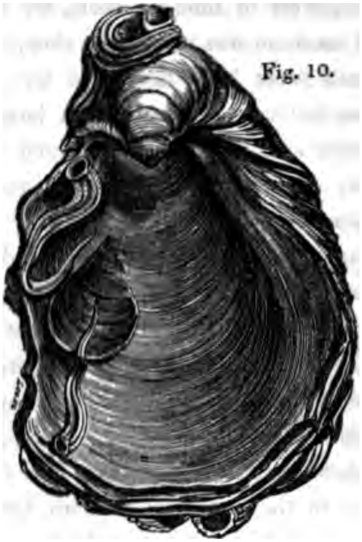
Having in the last chapter considered the forms of stratification so far as they are determined by the arrangement of inorganic matter, we may now turn our attention to the manner in which organic remains are distributed through stratified deposits. We should often be unable to detect any signs of stratifications or of successive deposition, if particular kinds of fossils did not occur here and there at certain depths in the mass. At one level, for example, bivalve shells of some one or more species predominate; at another, some univalve shell, and at a third, corals; while in some formations we find layers of vegetable matter separating strata.

It may appear inconceivable to a beginner how mountains, several thousand feet thick, can have become filled with fossils from top to bottom; but the difficulty is removed, when he reflects on the origin of stratification, as explained in the last chapter, and allows sufficient time for the accumulation of sediment. He must never lose sight of the fact that, during the process of deposition, each separate layer was once the uppermost, and covered immediately by the water in which aquatic animals lived. Each stratum, in fact, however far it may now lie beneath the surface, was once in the state of loose sand or soft mud at the bottom of the sea, in which shells and other bodies easily became enveloped.

By attending to the nature of these remains, we are often enabled to determine whether the deposition was slow or rapid, whether it took place in a deep or shallow sea, near the shore or far from land, and whether the water was salt, brackish, or fresh. Some limestones consist almost exclusively of corals, and their position has evidently been determined by the manner in which the zoophytes grew; for if the stratum be horizontal, the round spherical head of certain species is uppermost, and the point of attachment directed downwards. This arrangement is sometimes repeated throughout a great succession of strata. From what we know of the growth of similar zoophytes in modern reefs, we infer that the rate of increase was extremely slow, and some of the fossils must have flourished for ages like forest trees, before they attained so large a size. During these ages, the water remained clear and transparent, for such zoophytes cannot live in turbid water.

In like manner, when we see thousands of full-grown shells dispersed everywhere throughout a long series of strata, we cannot doubt that time was required for the multiplication of successive generations; and the evidence of slow accumulation is rendered more striking from the proofs, so often discovered, of fossil bodies having lain for a time on the floor of the ocean after death, before they were imbedded in sediment. Nothing, for example, is more common than to see fossil oysters in clay, with serpulæ, acorn shells, corals, and other creatures, attached to the inside of the valves, so that the mollusk was certainly not buried in argillaceous mud the moment it died. There must have been an interval during which it was still surrounded with clear water, when the testacea, now adhering to it, grew from an embryo state to full maturity. Attached shells which are merely external, like some of the serpulæ in the annexed figure (Fig. 10.), may often have grown upon an oyster or other shell while the animal within was still living; but if they are found on

Fig. 10.



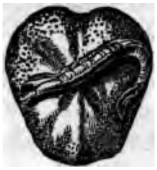
Fossil Gryphæa, covered both on the outside and inside with fossil serpulæ.

the inside, it could only happen after the death of the inhabitant of the shell which affords the support. Thus, in Fig. 10., it will be seen that two serpulæ have grown on the interior, one of them exactly on the place where the adductor muscle of the *Cryphæa* (a kind of oyster) was fixed.

Some fossil shells, even if simply attached to the *outside* of others, bear full testimony to the conclusion above alluded to, namely, that an interval elapsed between the death of the creature to whose shell they adhere, and the burial of the same in mud or sand. The sea-urchins, or

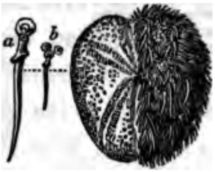
Echini, so abundant in white chalk, afford a good illustration. It is well known that these animals, when living, are invariably covered with numerous spines, which serve as organs of motion, and are supported by rows of tubercles, which last are only seen after the death of the sea-urchin, when the spines have dropped off. In Fig. 12. a living species of *Spatangus*, common on our coast, is represented with one half of its shell stripped of the spines. In Fig. 11. a fossil of the same genus from the white chalk of England shows the naked surface which the individuals of this family exhibit when denuded of their bristles. The full-grown *Serpula*, therefore, which now adheres externally, could not have begun to grow till the *Spatangus* had died, and the spines were detached.

Fig. 11.



Serpula attached to fossil Spatangus from the chalk.

Fig. 12.

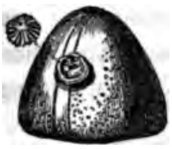


Recent Spatangus, with the spines removed from one side.

b. Spine and tubercles, nat. size.
a. The same magnified.

Now the series of events here attested by a single fossil may be carried a step further. Thus, for example, we often meet with a sea-urchin in the chalk (see Fig. 13.), which has fixed to it the lower valve of a *Crania*, a genus of bivalve mollusca. The upper valve (*b*, Fig. 13.) is almost invariably wanting, though occasionally found in a perfect state of preservation in white chalk at some distance. In this case, we see clearly that the sea-urchin first lived from youth to age, then died and lost its spines, which were carried away. Then the young *Crania* adhered to the bared shell, grew, and perished in its turn; after which the upper valve was separated from the lower before the *Echinus* became enveloped in chalky mud.

Fig. 13.

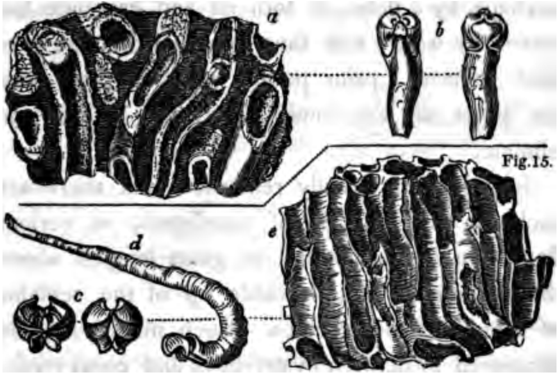


a. *Echinus* from the chalk, with lower valve of the *Crania* attached.
b. Upper valve of the *Crania* detached.

It may be well to mention one more illustration of the manner in which single fossils may sometimes throw light on a former state of things, both in the bed of the ocean and on some adjoining land. We meet with many fragments of wood bored by ship-worms at various depths in the clay on which London is built. Entire branches and stems of trees, several feet in length, are sometimes dug out, drilled all over by the holes of these borers, the tubes and shells of the mollusk still remaining in the cylindrical hollows. In Fig. 15., *e*, a representation is given of a piece of recent wood pierced by the *Teredo navalis*, or common shipworm, which destroys wooden piles and ships.

When the cylindrical tube *d* has been extracted from the wood, a shell is seen at the larger extremity, composed of two pieces, as shown at *c*. In like manner, a piece of fossil wood (*a*, Fig. 14.) has been perforated by an animal of a kindred but extinct genus, called *Teredina* by Lamarck. The calcareous tube of this mollusk was united and as it were soldered on to the valves of the shell (*b*), which therefore cannot be detached from the tube, like the valves of the recent *Teredo*.

Fig. 14.



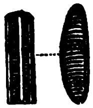
Fossil and recent wood drilled by perforating mollusca.

Fig. 14. *a.* Fossil wood from London clay, bored by *Teredina.*
b. Shell and tube of *Teredina personata,* the right-hand figure the ventral, the left the dorsal view.
Fig. 15. *e.* Recent wood bored by *Teredo.*
d. Shell and tube of *Teredo navalis,* from the same.
c. Anterior and posterior view of the valves of same, detached from the tube.

The wood in this fossil specimen is now converted into a stony mass, a mixture of clay and lime; but it must once have been buoyant and floating in the sea, when the *Teredinæ* lived upon it, perforating it in all directions. Again, before the infant colony settled upon the drift wood, the branch of a tree must have been floated down to the sea by a river, uprooted, perhaps, by a flood, or torn off and cast into the waves by wind: and thus our thoughts are carried back to a prior period, when the tree grew for years on dry land, enjoying a fit soil and climate.

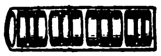
It has been already remarked that there are rocks in the interior of continents, at various depths in the earth, and at great heights above the sea, almost entirely made up of the remains of zoophytes and testacea. Such masses may be compared to modern oyster-beds and coral reefs; and, like them, the rate of increase must have been extremely gradual. But there are a variety of stony deposits in the earth's crust, now proved to have been derived from plants and animals, of which the organic origin was not suspected until of late years, even by naturalists. Great surprise was therefore created by the recent discovery of Professor Ehrenberg of Berlin, that a certain kind of siliceous stone, called tripoli, was entirely composed of millions of the skeletons or cases of microscopic animalcules. The substance alluded to has long been well known in the arts, being used in the form of powder for polishing stones and metals. It has been procured, among other places, from Bilin, in Bohemia, where a single stratum, extending over a wide area, is no less than 14 feet thick. This stone, when examined with a powerful microscope, is found to consist of the siliceous cases of infusoria, united together without any visible cement. It is difficult to convey an idea of their extreme minuteness; but Ehrenberg estimates that in the Bilin tripoli there are 41,000 millions of individuals of the *Gaillonella distans* (see Fig. 17.) in every cubic inch, which weighs about 220 grains, or about 187 millions in a single grain. At every stroke, therefore, that we make with this polishing powder, several millions, perhaps tens of millions, of perfect fossils are crushed to atoms.

Fig. 16.



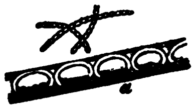
Bacillaria vulgaris?

Fig. 17.



Gaillonella distans.

Fig. 18.



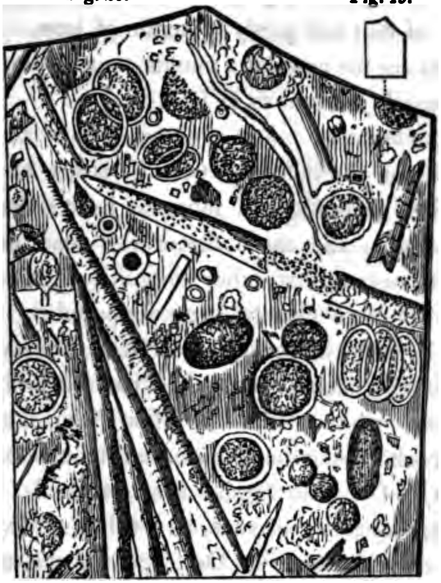
Gaillonella ferruginea.

These figures are magnified nearly 300 times, except the lower figure of G. ferruginea (Fig. 18. a), which is magnified 2000 times.

The shells or shields of these infusoria are of pure silex, and their forms are various, but very marked and constant in particular genera and species. Thus, in the family *Bacillaria* (see Fig. 16.), the fossil species preserved in tripoli are seen to exhibit the same divisions and transverse lines which characterize the living shells of kindred form. With these, also, the siliceous spiculæ or internal supports of the freshwater sponge, or *Spongilla* of Lamarck, are sometimes intermingled (see the needle-shaped bodies in Fig. 20.). These flinty cases and spiculæ, although hard, are very fragile, breaking like glass, and are therefore admirably adapted, when rubbed, for wearing down into a fine powder fit for polishing the surface of metals.

Besides the tripoli, which is formed exclusively of infusoria, there occurs in the upper part of the great stratum at Bilin another heavier and more compact stone, a kind of semi-opal, in which innumerable parts of infusoria and spiculæ of the *Spongilla* are filled with, and cemented together by, siliceous matter. It is supposed that the shells of the more delicate animalcules have been dissolved by water, and have thus given rise to this opal, in which the more durable fossils are preserved like insects in amber. This opinion is confirmed by the fact, that the small shells decrease in number and sharpness of outline in proportion as the opaline cement increases in quantity.

Fig. 20. Fig. 19.



Fragment of semi-opal from the great bed of tripoli, Bilin.

Fig. 19. Natural size.

Fig. 20. The same magnified, showing circular articulations of a species of *Gaillonella*, and spiculæ of *Spongilla.*

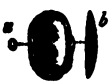
In the Bohemian tripoli above described, as in that of Planitz in Saxony, the species of infusoria are freshwater; but in other countries, as in the tripoli of the Isle of France, they are of marine species, and they all belong to formations of the *tertiary* period, which will be spoken of hereafter.

A well-known substance, called bog-iron ore, often met with in peat-mosses, has also been shown by Ehrenberg to consist of innumerable articulated threads, of a yellow ochre color, composed partly of flint and partly of oxide of iron. These threads are the cases of a minute animalcule, called *Gaillonella ferruginea* (Fig. 18.).

It is clear that much time must have been required for the accumulation of strata to which countless generations of infusoria have contributed their shells; and these discoveries lead us naturally to suspect that other deposits, of which the materials have usually been supposed to be inorganic, may in reality have been derived from microscopic organic bodies. That this is the case with the white chalk, has often been imagined, this rock having been observed to abound in a variety of marine fossils, such as shells, echini, corals, sponges, crustacea, and fishes. Mr. Lonsdale, on examining in Oct. 1835, in the museum of the Geological Society of London, portions of white chalk from different parts of England, found, on carefully pulverizing them in water, that what appear to the eye simply as white grains were, in fact, well-preserved fossils. He obtained about a thousand of these from each pound weight of chalk, some being fragments of minute corallines, others entire Foraminifera and Cytherinæ. The annexed drawings will give an idea of the beautiful forms of many of these bodies. The figures *a a* represent their natural size, but, minute as they seem, the smallest of them, such as *a*, Fig. 24., are gigantic in comparison with the cases of infusoria before mentioned.

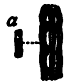
Cytherinæ and Foraminifera from the chalk.

Fig. 21.



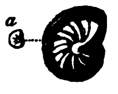
Cytherina.

Fig. 22.



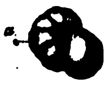
Portion of Nodosaria.

Fig. 23.



Lenticulina, Lam. (*Operculina*, D'Orb.)

Fig. 24.



Discorbis.

It has, moreover, been lately discovered, by Ehrenberg (1839), that the chambers into which these Foraminifera are divided are actually often filled with thousands of well-preserved infusoria, and other microscopic bodies, which abound in every minute grain of chalk. The bodies alluded to are calcareous; but others have been detected in the flints of the chalk, which, like the infusoria in tripoli, are siliceous. These forms are especially apparent in the white coating of flints, often accompanied by innumerable needle-shaped spiculæ of sponges; and the same are occasionally visible in the central parts of chalk flints, where they are of a lighter color. After reflecting on these discoveries, we are naturally led on to conjecture that, as the formless cement in the semi-opal of Bilin has been derived from the decomposition of animal remains, so also even those parts of chalk flints in which no organic structure can be recognised may nevertheless have constituted a part of microscopic animalcules.

"The dust we tread upon was once alive!"—BYRON.

How faint an idea does this exclamation of the poet convey of the real wonders of nature! for here we discover proofs, that the calcareous and siliceous dust of which hills are composed has not only been once alive, but almost every particle, albeit invisible to the naked eye, still retains the organic structure which, at periods of time incalculably remote, was impressed upon it by the powers of life.

As I have dwelt upon the proofs of the slowness with which fossiliferous strata in general have been produced, I may remark that some writers have argued, from the appearances of certain deposits containing coal, that sedimentary rocks of great thickness have been accumulated with rapidity. This conclusion has been drawn chiefly from a remarkable phenomenon,—the position of the trunks of fossil trees intersecting obliquely, and often at right angles, the planes of many strata. For a full examination of this question, the reader is referred to the chapter on the carboniferous formations, in the sequel; and I shall merely say here, that, although partial deposits have been thrown down in the spots where these fossil trees occur in a comparatively short lapse of time, yet we can by no means infer that a similar rate of increase of carboniferous rocks prevailed simultaneously over a wide area. On the other hand, the vegetable origin of coal is now universally admitted by geologists; and, when we discuss the probable manner in which the terrestrial plants from which it was derived were imbedded in marine shale and sandstone, we shall find it necessary to suppose a long succession of operations.

Freshwater and marine fossils.— Strata, whether deposited in salt or fresh water, have the same forms; but the fossils are very different in the two cases, because the aquatic animals which frequent lakes and rivers are distinct from those inhabiting the sea. In the northern part of the Isle of Wight is a formation, composed of marl and limestone, more than fifty feet thick, in which the shells are principally, if not all, of extinct species. Yet we recognise their freshwater origin, because they are of the same genera as those now abounding in ponds and lakes, either in our own country or in warmer latitudes.

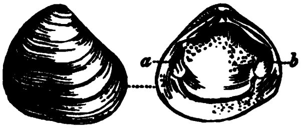
In many parts of France, as in Auvergne, for example, strata of limestone, marl, and sandstone occur, hundreds of feet thick, which contain exclusively freshwater and land shells, together with the remains of terrestrial quadrupeds. The number of land shells scattered through some of these freshwater deposits is exceedingly great; and there are even districts where the rocks scarcely contain any other fossils except snail-shells (*helices*) ; as, for instance, the limestone on the left bank of the Rhine, between Mayence and Worms, at Oppenheim, Findheim, Budenheim, and other places. In order to account for this phenomenon, the geologist has only to examine the small deltas of torrents which enter the Swiss lakes when the waters are low, such as the newly-formed plain where the Kander enters the Lake of Thun. He there sees sand and mud strewed over with innumerable dead land shells, which have been brought down from valleys in the Alps in the preceding spring, during the melting of the snows. Again, if we search the sands on the borders of the Rhine, in the lower part of its course, we find countless land shells mixed with others of species belonging to lakes, stagnant pools, and marshes. These individuals have been washed away from the alluvial plains of the great river and its tributaries, some from mountainous regions, others from the low country.

Although freshwater formations are often of great thickness, yet they are usually very limited in area when compared to marine deposits, just as lakes and estuaries are of small dimensions in comparison with seas.

We may distinguish a freshwater formation, first, by the absence of many fossils almost invariably met with in marine strata. For example, there are no corals, no sea-urchins, and scarcely any other zoophytes; no chambered shells, such as the nautilus, nor microscopic Foraminifera. But it is chiefly by attending to the forms of the mollusca that we are guided in determining the point in question. In a freshwater deposit, the number of individual shells is often as great, if not greater, than in a marine stratum; but there is a smaller variety of species and genera. This might be anticipated from the fact that the genera and species of recent freshwater and land shells are few when contrasted with the marine. Thus, the genera of true mollusca according to Blainville's system, excluding those of extinct species and those without shells, amount to about 200 in number, of which the terrestrial and freshwater genera scarcely form more than a sixth.*

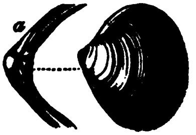
Almost all bivalve shells, or those of acephalous mollusca, are marine, about ten only out of ninety genera being freshwater. Among these last, the four most common forms, both recent and

Fig. 25.



Cyclas obovata; fossil. Hants.

Fig. 26.



Cyrena trigonula; fossil. Grays, Essex.

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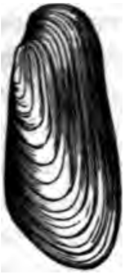
* See Synoptic Table, in Blainville's Malacologie.

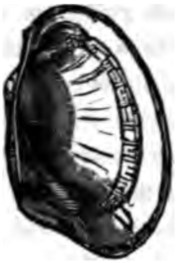
fossil, are *Cyclas*, *Cyrena*, *Unio*, and *Anodonta* (see figures); the two first and two last of which are so nearly allied as to pass into each other.

Fig. 27.



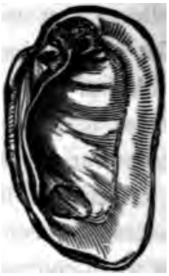
Anodonta Cordierii; fossil. Paris.

Fig. 28.



Anodonta latimargi-natus; recent. Bahia.

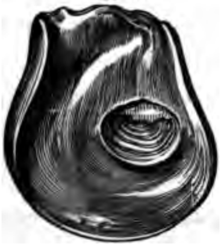
Fig. 29.



Unio littoralis; recent. Auvergne.

Lamarck divided the bivalve mollusca into the *Dimyary*, or those having two large muscular impressions in each valve, as *a b* in the Cyclas, Fig. 25., and the *Monomyary*, such as the oyster and scallop, in which there is only one of these impressions, as is seen in Fig. 30. Now, as none of these last, or the unimuscular bivalves, are freshwater, we may at once presume a deposit in which we find any of them to be marine.

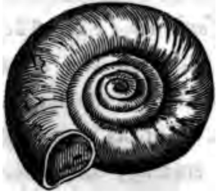
Fig 30.



Gryphæa incurva, Sow. (*G. arcuata*, Lam.) upper valve. Lias.

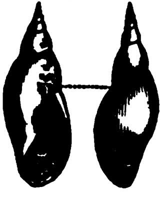
The univalve shells most characteristic of freshwater deposits are, *Planorbis*, *Limnea*, and *Paludina*. (See figures.) But to these are occasionally added *Physa*, *Succinea*, *Ancylus*, *Valvata*, *Melanopsis*, *Melania*, and *Neritina*. (See figures.)

Fig. 31.



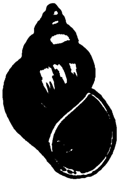
Planorbis euomphalus: fossil. Isle of wight.

Fig. 32.



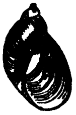
Limnea longiscata; fossil. Hants.

Fig. 33.



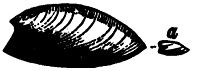
Paludina lenta; fossil. Hants.

Fig. 34.



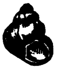
Succinea amphibia; fossil. Loess, Rhine.

Fig. 35.



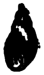
Ancylus elegans; fossil. Hants.

Fig. 36.



Valvata; fossil. Grays, Essex.

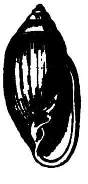
Fig. 37.



Physa hypnorum; recent.

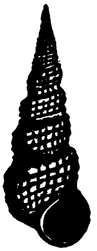
In regard to one of these, the *Ancylus* (Fig. 35.), Mr. Gray observes, that it sometimes differs

Fig. 38.



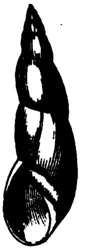
Auricula; recent. Ava.

Fig. 39.



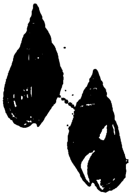
Melania inquinata. Paris Basin.

Fig. 40.



Physa columnaris. Paris Basin.

Fig. 41.

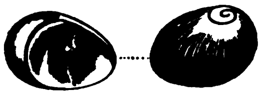


Melanopsis buccinoidea; recent. Asia.

in no respect from the marine *Siphonaria*, except in the animal. The shell, however, of the *Ancylus* is usually thinner.*

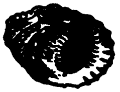
Some naturalists include *Neritina* (Fig. 42.) and the marine *Nerita* (Fig. 43.) in the same genus, it being scarcely possible to distinguish the two by good generic characters. But, as a general rule, the fluviatile species are smaller, smoother,

Fig. 42.



Neritina globulus. Paris Basin.

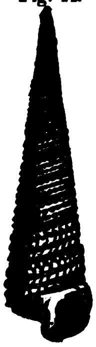
Fig. 43.



Nerita granulosa. Paris Basin.

and more globular than the marine; and they have never, like the *Neritæ*, the inner margin of the outer lip toothed or crenulated. (See Fig. 43.)

Fig. 44.



Cerithium cinctum. Paris Basin.

A few genera, among which *Cerithium* (Fig. 44.) is the most abundant, are common to both rivers and the sea, having species peculiar to each. Other genera, like *Auricula* (Fig. 38.), are amphibious, frequenting marshes especially, near the sea.

The terrestrial shells are all univalves. The most abundant genera among these, both in a recent and fossil state, are *Helix* (Fig. 45.), *Cyclostoma*, *Pupa* (Fig. 46.),

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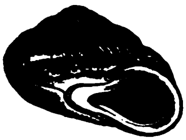
* Gray, Phil. Trans., 1835, p. 302.

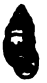
Clausilia (Fig. 47.), *Bulimus* (Fig. 48.), and *Achatina*; which two last are nearly allied and pass into each other.

Fig. 45.



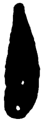
Helix Turonensis.
Faluns, Touraine.

Fig. 46.



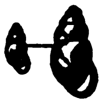
Pupa tridens.
Loess.

Fig. 47.



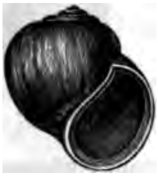
Clausilia bidens.
Loess.

Fig. 48.



Bulimus lubricus.
Loess, Rhine.

Fig. 49.



Ampullaria glauca,
from the Jumna.

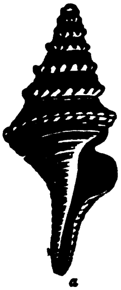
The *Ampullaria* (Fig. 49.) is another genus of shells, inhabiting rivers and ponds in hot countries. Many fossil species have been referred to this genus, but they have been found chiefly in marine formations, and are suspected by some conchologists to belong to *Natica* and other marine genera.

All univalve shells of land and fresh-water species with the exception of *Melanopsis* (Fig. 41.), and *Achatina*, which has a slight indentation, have entire mouths; and this circumstance may often serve as a convenient rule for distinguishing fresh-water from marine strata; since, if any univalves occur of which the mouths are not entire, we may presume that the formation is marine. The aperture is said to be entire in such shells as the *Am-*

pullaria and the land shells figured in page 65., when its outline is not interrupted by an indentation or notch such as that in *Ancillaria* (Fig. 51.); or is not prolonged into a canal, as that seen at *a* in *Pleurotoma* (Fig. 50.).

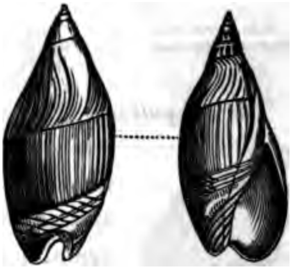
The mouths of a large proportion of the marine univalves have either these notches or canals, and almost all these species are carniverous; whereas nearly all testacea having entire mouths, are plant-eaters, whether the species be marine, freshwater, or terrestrial.

Fig. 50.



Pleurotoma rotata. Subap. hills, Italy.

Fig. 51.



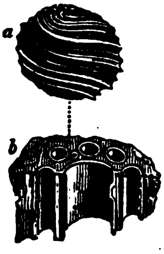
Ancillaria subulata. London clay.

There is, however, one genus which affords an occasional exception to one of the above rules. The *Cerithium* (Fig. 44.), although provided with a short canal, comprises some species which inhabit salt, others brackish, and others fresh water, and they are said to be all plant-eaters.

Among the fossils very common in freshwater deposits, are the shells of *Cypris*, a minute crustaceous animal, having a shell much resembling that of the bivalve mollusca.* Many minute living species of this genus swarm in lakes and stagnant pools in Great Britain; but their shells are not, if considered separately, conclusive as to the freshwater origin of a deposit, because another kindred genus of the same order, the *Cytherina* of Lamarck (see Fig. 21. p. 57.), inhabits salt water; and although the animal differs slightly, the shell is undistinguishable from that of the *Cypris*.

The seed-vessels of *Chara*, a genus of aquatic plants, are very frequent in freshwater strata. These seed-vessels were called, before their true

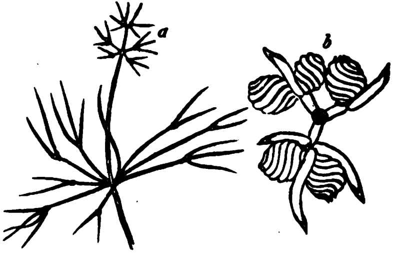
Fig. 52.



Chara medicaginula; fossil. Isle of Wight.

a. Seed-vessel, magnified 20 diameters.
b. Stem, magnified.

Fig. 53.



Chara elastica; recent. Italy.

a. Sessile seed-vessel between the division of the leaves of the female plant.
b. Transverse section of a branch, with five seed-vessels magnified, seen from below upwards.

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* For figures of recent species, see Index, "*Cypris*."

nature was known, gyrogonites, and were supposed to be shells. (See Fig. 52. *a.*)

The *Charæ* inhabit the bottom of lakes and ponds, and flourish mostly where the water is charged with carbonate of lime. Their seed-vessels are covered with a very tough integument, capable of resisting decomposition; to which circumstance we may attribute their abundance in a fossil state. The annexed figure (Fig. 53.) represents a branch of one of many new species found by Professor Amici in the lakes of northern Italy, The seed-vessel in this plant is more globular than in the British *Charæ*, and therefore more nearly resembles in form the extinct fossil species found in England, France, and other countries. The stems, as well as the seed-vessels, of these plants occur both in modern shell marl and in ancient freshwater formations. They are generally composed of a large tube surrounded by smaller tubes; the whole stem being divided at certain intervals by transverse partitions or joints. (See *b*, Fig. 52.)

It is not uncommon to meet with layers of vegetable matter, impressions of leaves, and branches of trees, in strata containing freshwater shells; and we also find occasionally the teeth and bones of land quadrupeds, of species now unknown. The manner in which such remains are occasionally carried by rivers into lakes, especially during floods, has been fully treated of in the "Principles of Geology."*

The remains of fish are occasionally useful in determining the freshwater origin of strata. Certain genera, such as carp, perch, pike, and loach, (*Cyprinus*, *Perca*, *Esox*, and *Cobitis*,) as also *Lebias*, being peculiar to freshwater. Other genera contain some freshwater and some marine species, as *Cottus*, *Mugil*, and *Anguilla*, or eel. The rest are either common to rivers and the sea, as the salmon; or are exclusively characteristic of salt water. The above observations respecting fossil fishes are applicable only to the more modern or tertiary deposits; for in the more ancient rocks the forms depart so widely from those of existing fishes, that it is very difficult, at least in the present state of science, to derive any positive information from icthyolites, respecting the element in which strata were deposited.

The alternation of marine and freshwater formations, both on a small and large scale, are facts well ascertained in geology. When it occurs on a small scale, it may have arisen from the alternate occupation of certain spaces by river water and the sea; for in the flood season the river forces back the ocean and freshens it over a large area, depositing at the same time its sediment; after which the salt water again returns, and, on resuming its former place, brings with it sand, mud, and marine shells.

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* See Index, "Fossilization."

There are also lagoons at the mouths of many rivers, as the Nile and Mississippi, which are divided off by bars of sand from the sea, and which are filled with salt and fresh water by turns. They often communicate exclusively with the river for months, years, or even centuries; and then, a breach being made in the bar of sand, they are for long periods filled with salt water.

The Lym-Fiord in Jutland offers an excellent illustration of analogous changes; for, in the course of the last thousand years, the western extremity of this long frith, which is 120 miles in length, including its windings, has been four times fresh and four times salt, a bar of sand between it and the ocean having been as often formed and removed. The last irruption of salt water happened in 1824, when the North Sea entered, killing all the freshwater shells, fish, and plants; and from that time to the present, the sea-weed, *Fucus vesiculosus*, together with oysters and other marine mollusca, have succeeded the *Cyclas*, *Limnea*, *Paludina*, and *Charæ*.*

But changes like these in the Lym-Fiord, and those before mentioned as occurring at the mouths of great rivers, will only account for some cases of marine deposits resting on freshwater strata.

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* See Principles, Index, "Lym-Fiord."

When we find, as in the southeast of England, a great series of freshwater beds, resting upon one marine formation of great thickness, and again covered by another more than 1000 feet thick, we shall find it necessary to seek for a different explanation of the phenomena.*

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* See Chap. on Wealden.

CHAPTER IV.

CONSOLIDATION OF STRATA AND PETRIFACTION OF FOSSILS.

Chemical and mechanical deposits — Cementing together of particles — Hardening by exposure to air — Concretionary nodules — Consolidating effects of pressure — Mineralization of organic remains — Impressions and casts how formed — Fossil wood — Göppert's experiments — Precipitation of stony matter most rapid where putrefaction is going on — Source of lime in solution — Silex derived from decomposition of felspar — Proofs of the lapidification of some fossils soon after burial, of others when much decayed.

Having spoken in the preceding chapters of the forms of stratification, both as dependent on the deposition of inorganic matter and the distribution of fossils, I may next treat of the consolidation of stratified rocks, and the petrifaction of imbedded organic remains.

Chemical and mechanical deposits.—A distinction has been made by geologists between deposits of a chemical, and those of a mechanical, origin. By the latter name are designated beds of mud, sand, or pebbles produced by the action of running water, also accumulations of stones and scoriæ thrown out by a volcano, which have fallen into their present place by the force of gravitation.

But the matter which forms a chemical deposit has not been mechanically suspended in water, but in a state of solution until separated by chemical action. In this manner carbonate of lime is often thrown to the bottom of lakes and seas in a solid form, as may be well seen in many parts of Italy, where mineral springs abound, and where the calcareous stone, called travertin, is deposited. In these springs the lime is usually held in solution by an excess of carbonic acid, or by heat if it be a hot spring, until the water, on issuing from the earth, cools or loses part of its acid. The calcareous matter then falls down in a solid state, encrusting shells, fragments of wood and leaves, and binding them together.*

In coral reefs, large masses of limestone are formed by the stony skeletons of zoophytes; and these, together with shells, become cemented together by carbonate of lime, part of which is probably furnished to the sea-water by the decomposition of dead corals. Even shells of which the animals are still living, on these reefs, are very commonly found to be encrusted over with a hard coating of limestone.†

If sand and pebbles are carried by a river into the sea, and these are bound together immediately by carbonate of lime, the deposit may be described as of a mixed origin, partly chemical, and partly mechanical.

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* See Principles, Index, "Calcareous Springs," &c.

† Ibid. "Travertin," "Coral reefs," &c.

Now, the remarks already made in Chapter II. on the original horizontality of strata are strictly applicable to mechanical deposits, and only partially to those of a mixed nature. Such as are purely chemical may be formed on a very steep slope, or may even encrust the vertical walls of a fissure, and be of equal thickness throughout; but such deposits are of small extent, and for the most part confined to vein-stones.

Cementing of particles. — It is chiefly in the case of calcareous rocks that solidification takes place at the time of deposition. But there are many deposits in which a cementing process comes into operation long afterwards. We may sometimes observe, where the water of ferruginous or calcareous springs has flowed through a bed of sand or gravel, that iron or carbonate of lime has been deposited in the interstices between the grains or pebbles, so that in certain places the whole has been bound together into a stone, the same set of strata remaining in other parts loose and incoherent.

Proofs of a similar cementing action are seen in a rock at Kelloway in Wiltshire. A peculiar band of sandy strata, belonging to the group called Oolite by geologists, may be traced through several counties, the sand being for the most part loose and unconsolidated, but becoming stony near Kelloway. In this district there are numerous fossil shells which have decomposed, having for the most part left only their casts. The calcareous matter hence derived has evidently served, at some former period, as a cement to the siliceous grains of sand, and thus a solid sandstone has been produced. If we take fragments of many other argillaceous grits, retaining the casts of shells, and plunge them into dilute muriatic or other acid, we see them immediately changed into common sand and mud; the cement of lime, derived from the shells, having been dissolved by the acid.

Traces of impressions and casts are often extremely faint. In some loose sands of recent date we meet with shells in so advanced a stage of decomposition as to crumble into powder when touched. It is clear that water percolating such strata may soon remove the calcareous matter of the shell; and, unless circumstances cause the carbonate of lime to be again deposited, the grains of sand will not be cemented together; in which case no memorial of the fossil will remain. The absence of organic remains from many aqueous rocks may be thus explained.

In what manner silex and carbonate of lime may become widely diffused in small quantities through the waters which permeate the earth's crust will be spoken of presently, when the petrifaction of fossil bodies is considered; but I may remark here that such waters are always passing in the case of thermal springs from hotter to colder parts of the interior of the earth; and as often as the temperature of the solvent is lowered, mineral matter has a tendency to separate from it and solidify. Thus a stony cement is often supplied to any sand, pebbles, or fragmentary mixture. In some conglomerates, like the pudding-stone of Hertfordshire, pebbles of flint and grains of sand are united by a siliceous cement so firmly, that if a block be fractured the rent passes as readily through the pebbles as through the cement.

It is probable that many strata became solid at the time when they emerged from the waters in which they were deposited, and when they first formed a part of the dry land. A well known fact seems to confirm this idea; by far the greater number of the stones used for building and road making are much softer when first taken from the quarry than after they have been long exposed to the air. Hence it is found desirable to shape the stones which are to be used in architecture while they are yet soft and wet, and while they contain their "quarry-water," as it is called; also to break up stone intended for roads when soft, and then leave it to dry in the air for months, that it may harden. Such induration may perhaps be accounted for by supposing the water, which penetrates the minutest pores of rocks, to deposit on evaporation carbonate of lime, iron, silex, and other minerals previously held in solution. These particles, on crystallizing, would not only be deprived themselves of freedom of motion, but would also bind together other portions of the rock which before were loosely aggregated. On the same principle wet sand and mud become as hard as stone when frozen; because one ingredient of the mass, namely, the water, has crystallized, so as to hold firmly together all the separate particles of which the loose mud and sand were composed.

Dr. MacCulloch mentions a sandstone in Sky, which may be moulded like dough when first found; and another from China, which is compressible by the hand when immersed in water. But it is not merely these compounds which readily admit water to penetrate into them; some simple minerals, says the same writer, which are rigid and as hard as glass in our cabinets, are often flexible and soft in their native beds; this is the case with asbestos, sahlite, tremolite, and calcedony, and it is reported also to happen in the case of the beryl.*

The marl recently deposited at the bottom of Lake Superior, in North America, is soft, and often filled with freshwater shells; but if a piece be taken up and dried, it becomes so hard that it can only be broken by a smart blow of the hammer. If the lake therefore was drained, such a deposit would be found to consist of strata of marlstone, like that observed in many ancient European formations, and like them containing freshwater shells.*

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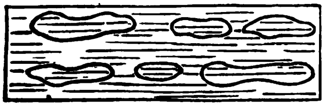
* Dr. MacCulloch, Syst. of Geol. vol. i. p. 123.

It is probable that some of the heterogeneous materials which rivers transport to the sea may at once set under water, like the artificial mixture called pozzolana, which consists of fine volcanic sand charged with about 20 per cent. of iron, and the addition of a small quantity of lime. This substance hardens, and becomes a solid stone in water, and was used by the Romans in constructing the foundations of buildings in the sea.

Consolidation in these cases is brought about by the action of chemical affinity on finely comminuted matter previously suspended in water. After deposition similar particles seem to exert a mutual attraction on each other, and congregate together in particular spots, forming lumps, nodules, and concretions. Thus in many argillaceous deposits there are calcareous balls, or spherical concretions, ranged in layers parallel to the general stratification; an arrangement which took place after the shale or marl had been thrown down in successive

* Princ. of Geol., Index, "Superior, Lake."

Fig. 54.

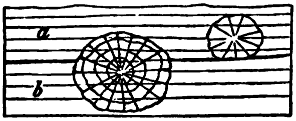


Calcareous nodules in Lias.

laminæ; for these laminæ are often traced in the concretions, remaining parallel to those of the surrounding unconsolidated rock. (See Fig. 54.) Such nodules of limestone have often a shell or other foreign body in the centre.*

Among the most remarkable examples of concretionary structure are those described by Professor Sedgwick as abounding in the magnesian limestone of the north of England. The spherical balls are of various sizes, from that of a pea to a diameter of several feet, and they have both a concentric and radiated structure, while at the same time the laminæ of original deposition pass uninterruptedly through them. In some cliffs this limestone resembles a great irregular pile of cannon balls. Some of the globular masses have their centre in one stratum, while a portion of their exterior passes through to the stratum above or below. Thus the larger spheroid in the annexed section (Fig. 55.) passes from the stratum *b* upwards into *a*. In this instance we must suppose the deposition of a series of minor layers, first

Fig. 55.



Spheroidal concretions in magnesian limestone.

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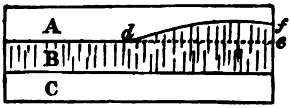
* See De la Beche's Geological Researches, p. 95.

forming the stratum *b*, and afterwards the incumbent stratum *a*; then a movement of the particles took place, and the carbonates of lime and magnesia separated from the more impure and mixed matter forming the still unconsolidated parts of the stratum. Crystallization, beginning at the centre, must have gone on forming concentric coats around the original nucleus without interfering with the laminated structure of the rock.

When the particles of rocks have been thus re-arranged by chemical forces, it is sometimes difficult or impossible to ascertain whether certain lines of division are due to original deposition or to the subsequent aggregation of similar particles. Thus suppose three strata of grit, A, B, C, are charged unequally with calcareous matter, and that B is the most calcareous. If consolidation takes place in B, the concretionary action may spread upwards into a part of A, where the carbonate of lime is more abundant than in the rest; so that a mass, *d*, *e*, *f*, forming a portion of the superior stratum, becomes united with B into one solid mass of stone. The original line of division, *d*, *e*, being thus effaced, the line *d*, *f*, would generally be considered as the surface of the bed B, though not strictly a true plane of stratification.

Fig. 56.



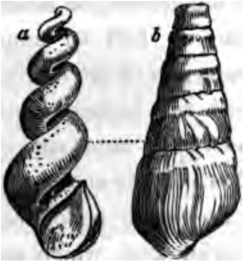
Pressure and heat. — When sand and mud sink to the bottom of a deep sea, the particles are not pressed down by the enormous weight of the incumbent ocean; for the water which becomes mingled with the sand and mud, resists pressure with a force equal to that of the column of fluid above. The same happens in regard to organic remains which are filled with water under great pressure as they sink, otherwise they would be immediately crushed to pieces and flattened. Nevertheless, if the materials of a stratum remain in a yielding state, and do not set or solidify, they will be gradually squeezed down by the weight of other materials successively heaped upon them, just as soft clay or loose sand on which a house is built may give way. By such downward pressure particles of clay, sand, and marl, may become packed into a smaller space, and be made to cohere together permanently.

Analogous effects of condensation may arise when the solid parts of the earth's crust are forced in various directions by those mechanical movements afterwards to be described, by which strata have been bent, broken, and raised above the level of the sea. Rocks of more yielding materials must often have been forced against others previously consolidated, and, thus compressed, may have acquired a new structure.

But the action of heat at various depths in the earth is probably the most powerful of all causes in hardening sedimentary strata. To this subject I shall refer again when treating of the metamorphic rocks, and of the slaty and jointed structure.

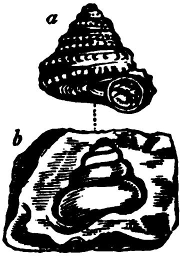
Mineralization of organic remains.—The changes which fossil organic bodies have undergone since they were first imbedded in rocks, throw much light on the consolidation of strata. Fossil shells in some modern deposits have been scarcely altered in the course of centuries, having simply lost a part of their animal matter. But in other cases the shell has disappeared, and left an impression only of its exterior, or a cast of its interior form, or thirdly, a cast of the shell itself, the original matter of which has been removed. These different forms of fossilization may easily be understood if we examine the mud recently thrown out from a pond or canal in which there are shells. If the mud be argillaceous, it acquires consistency on drying, and on breaking open a portion of it we find that each shell has left impressions of its external form. If we then remove the shell itself, we find within a solid nucleus of clay, having the form of the interior of the shell. This form is often very different from that of the outer shell. Thus a cast such as *a*, Fig. 57., commonly called a fossil screw, would never be suspected by an inexperienced conchologist to be the internal shape of the fossil univalve, *b*, Fig. 57. Nor should we have imagined at first sight that the shell *a* and the cast *b*, Fig. 58., were different parts of the same fossil. The reader will observe in the last-mentioned figure (*b*, Fig. 58.), that an empty space shaded dark, which the *shell itself* once occupied, now intervenes between the enveloping stone and the cast of the smooth interior of the whorls. In such cases the shell has been dissolved and the component particles removed by water percolating the rock. If the nucleus were taken out a hollow mould would remain, on which the external form of the shell with its tubercles and striæ, as seen in *a*, Fig. 58., would be seen embossed. Now if the space alluded to between the nucleus and the impression, instead of being left empty, has been filled up with calcareous spar, pyrites, or other mineral, we then obtain from the mould an exact

Fig. 57.



Phasianella Heddingtonensis, and cast of the same. Coral Rag.

Fig. 58.

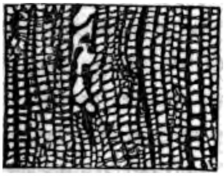


Trochus Anglicus and cast. Lias.

cast both of the external and internal form of the original shell. In this manner silicified casts of shells have been formed; and if the mud or sand of the nucleus happen to be incoherent, or soluble in acid, we can then procure in flint an empty shell which is the exact counterpart of the original. This cast may be compared to a bronze statue, representing merely the superficial form, and not the internal organization; but there is another description of petrifaction by no means uncommon, and of a much more wonderful kind, which may be compared to certain anatomical models in wax, where not only the outward forms and features, but the nerves, blood-vessels, and other internal organs are also shown. Thus we find corals, originally calcareous, in which not only the general shape, but also the minute and complicated internal organization are retained in flint.

Such a process of petrifaction is still more remarkably exhibited in fossil wood, in which we often perceive not only the rings of annual growth, but all the minute vessels and medullary rays. Many of the minute pores and fibres of plants, and even those spiral vessels which in the living vegetable can only be discovered by the microscope, are preserved. Among many instances I may mention a fossil tree, seventy-two feet in length, found at Gosforth near Newcastle, in sandstone strata associated with coal. By cutting a transverse slice so thin as to transmit light, and magnifying it about fifty-five times, the texture seen in Fig. 59 is exhibited. A texture equally minute and complicated has been observed in the wood of large trunks of fossil trees found in the Craigleith quarry near Edinburgh, where the stone was not in the slightest degree siliceous, but consisted chiefly of carbonate of lime, with oxide of iron, alumina, and carbon. In some examples the woody fibre is partially preserved, but it has entirely vanished from others.

Fig. 59.



Texture of a tree from the coal-strata, magnified. (Witham.)

In attempting to explain the process of petrifaction in such cases, we may first assume that strata are very generally permeated by water charged with minute portions of calcareous, siliceous, and other earths in solution. In what manner they become so impregnated will be afterwards considered. If an organic substance is exposed in the open air to the action of the sun and rain, it will in time putrefy, or be dissolved into its component elements, which consist chiefly of oxygen, hydrogen, and carbon. These will readily be absorbed by the atmosphere or be washed away by rain, so that all vestiges of the dead animal or plant disappear. But if the same substances be submerged in water, they decompose more gradually; and if buried in earth, still more slowly, as in the familiar example of wooden piles or other buried timber. Now, if as fast as each particle is set free by putrefaction in a fluid or gaseous state, a particle equally minute of carbonate of lime, flint, or other mineral, is at hand and ready to be precipitated, we may imagine this inorganic matter to take the place just before left unoccupied by the organic molecule. In this manner a cast of the interior of certain vessels may first be taken, and afterwards the walls of the same may decay and suffer a like transmutation. Yet when the whole is lapidified, it may not form one homogeneous mass of stone or metal. Some of the original ligneous, osseous, or other organic elements may remain mingled in certain parts, or the lapidifying substance itself may be differently colored at different times, or so crystallized as to reflect light differently, and thus the texture of the original body may be faithfully exhibited.

But the student will ask whether, on chemical principles, we have reason to expect that mineral matter will be thrown down precisely in those spots where organic decomposition is in progress? The following curious experiments may serve to illustrate this point. Professor Göppert of Breslau attempted recently to imitate the natural process of petrifaction. For this purpose he steeped a variety of animal and vegetable substances in waters, some holding siliceous, others calcareous, others metallic matter in solution. He found that in the period of a few weeks, or even days, the organic bodies thus immersed were mineralized to a certain extent. Thus, for example, thin vertical slices of deal, taken from the Scotch fir (*Pinus sylvestris*), were immersed in a moderately strong solution of sulphate of iron. When they had been thoroughly soaked in the liquid for several days, they were dried and exposed to a red-heat until the vegetable matter was burnt up and nothing remained but an oxide of iron, which was found to have taken the form of the deal so exactly that even the dotted vessels peculiar to this family of plants, and resembling those in Fig. 59., were distinctly visible under the microscope.

Another accidental experiment has been recorded by Mr. Pepys in the Geological Transactions.* An earthen pitcher containing several quarts of sulphate of iron had remained undisturbed and unnoticed for about a twelvemonth in the laboratory. At the end of this time when the liquor was examined an oily appearance was observed on the surface, and a yellowish powder, which proved to be sulphur, together with a quantity of small hairs. At the bottom were discovered the bones of several mice in a sediment consisting of small grains of pyrites, others of sulphur, others of crystallized green sulphate of iron, and a black muddy oxide of iron. It was evident that some mice had accidentally been drowned in the fluid, and by the mutual action of the animal matter and the sulphate of iron on each other, the metallic sulphate had been deprived of its oxygen; hence the pyrites and the other compounds were thrown down. Although the mice were not mineralized, or turned into pyrites, the phenomenon shows how mineral waters, charged with sulphate of iron, may be deoxydated on coming in contact with animal matter undergoing putrefaction, so that atom after atom of pyrites may be precipitated, and ready, under favorable circumstances, to replace the oxygen, hydrogen, and carbon into which the original body would be resolved.

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* Vol. i. p. 399. first series.

The late Dr. Turner observes, that when mineral matter is in a " nascent state," that is to say, just liberated from a previous state of chemical combination, it is most ready to unite with other matter, and form a new chemical compound. Probably the particles or atoms just set free are of extreme minuteness, and therefore move more freely, and are more ready to obey any impulse of chemical affinity. Whatever be the cause it clearly follows, as before stated, that where organic matter newly imbedded in sediment is decomposing, there will chemical changes take place most actively.

An analysis was lately made of the water which was flowing off from the rich mud deposited by the Hooghly river in the Delta of the Ganges after the annual inundation. This water was found to be highly charged with carbonic acid gas holding lime in solution.[*] Now if newly deposited mud is thus proved to be permeated by mineral matter in a state of solution, it is not difficult to perceive that decomposing organic bodies, naturally imbedded in sediment, may as readily become petrified as the substances artificially immersed by Professor Gŏppert in various fluid mixtures.

It is well known that the water of springs, or that which is continually percolating the earth's crust, is rarely free from a slight admixture either of iron, carbonate of lime, sulphur, flint, potash, or some other earthy, alkaline, or metallic ingredient. Hot springs in particular are copiously charged with one or more of these elements; and it is only in their waters that silex is found in abundance. In certain cases, therefore, especially in volcanic regions, we may imagine the flint of silicified wood and corals to have been supplied by the waters of thermal springs. In other instances, as in tripoli and chalk-flint, it may have been derived in great part, if not wholly, from the decomposition of infusoria, sponges, and other bodies. But even if this be granted, we have still to inquire whence a lake or the ocean can be constantly replenished with the siliceous matter so abundantly withdrawn from it by the secretions of these zoophytes.

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[*] Piddington, Asiat. Research. vol. xviii. p. 226.

In regard to carbonate of lime there is no difficulty, because not only are calcareous springs very numerous, but even rain-water has the power of dissolving a minute portion of the calcareous rocks over which it flows. Hence marine corals and mollusca may be provided by rivers with the materials of their shells and solid supports. But pure silex, even when reduced to the finest powder and boiled, is insoluble in water. Nevertheless Dr. Turner has well explained, in an essay on the chemistry of geology,* how the decomposition of felspar may be a source of silex in solution. He has remarked that the siliceous earth, which constitutes more than half the bulk of felspar, is intimately combined with alumine, potash, and some other elements. The alkaline matter of the felspar has a chemical affinity for water, as also for the carbonic acid which is more or less contained in the waters of most springs. The water therefore carries away alkaline matter, and leaves behind a clay consisting of alumine and flint. But this residue of the decomposed mineral, which in its purest state is called porcelain-clay, is found to contain only a small proportion of the silica which existed in the original felspar. The other part therefore must have been dissolved and removed; and this can be accounted for in two ways, first, because silex when combined with an alkali is soluble in water; secondly, because silex in what is technically called its nascent state is also soluble in water. Hence an endless supply of silica is afforded to rivers and the waters of the sea. For the felspathic rocks are universally distributed, constituting as they do, so large a proportion of the volcanic, plutonic, and metamorphic formations. Even where they chance to be absent in mass, they rarely fail to occur in the superficial gravel or alluvial deposits of the basin of every large river.

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* Jam. Ed. New Phil. Journ. No. 30. p. 246.

The disintegration of mica also, another mineral which enters largely into the composition of granite and various sandstones, may yield silex which may be dissolved in water, for nearly half of this mineral consists of silica, combined with alumine, potash, and about a tenth part of iron. The oxidation of this iron in the air is the principal cause of the waste of mica.

We have still, however, much to learn before the conversion of fossil bodies into stone is fully understood. Some phenomena seem to imply that the mineralization must proceed with considerable rapidity, for stems of a soft and succulent character, and of a most perishable nature, are preserved in flint; and there are instances of the complete silicification of the young leaves of a palm-tree when just about to shoot forth, and in that state which in the West Indies is called the cabbage of the palm.* It may, however, be questioned whether in such cases there may not have been some antiseptic quality in the water which retarded putrefaction, so that the soft parts of the buried substance may have remained for a long time without disintegration, like the flesh of bodies imbedded in peat.

Mr. Stokes has pointed out examples of petrifactions in which the more perishable, and others where the more durable portions of wood are preserved. These variations, he suggests, must doubtless have depended on the time when the lapidifying mineral was introduced. Thus, in certain silicified stems of palm-trees, the cellular tissue, that most destructible part, is in good condition, all signs of the hard woody fibre having disappeared, and the spaces once occupied by it being hollow or filled with agate. Here, petrifaction must have commenced soon after the wood was exposed to the action of moisture, and the supply of mineral matter must then have failed, or the water have become too much diluted before the woody fibre decayed. But when this fibre is alone discoverable, we must suppose that an interval of time elapsed before the commencement of lapidification, during which the cellular tissue was obliterated. When both structures, namely, the cellular and the woody fibre, are preserved, the process must have commenced at an early period, and continued without interruption till it was completed throughout.*

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* Stokes, Geol. Trans. vol. v. p. 212. second series.

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* Stokes, Geol. Trans. vol. v. p. 212. second series.

CHAPTER V.

ELEVATION OF STRATA ABOVE THE SEA — HORIZONTAL AND INCLINED STRATIFICATION.

Why the position of marine strata, above the level of the sea, should be referred to the rising up of the land, not to the going down of the sea — Upheaval of extensive masses of horizontal strata — Inclined and vertical stratification — Anticlinal and synclinal lines — Bent strata in east of Scotland — Theory of folding by lateral movement — Creeps — Dip and strike — Structure of the Jura — Various forms of outcrop — Rocks broken by flexure — Inverted position of disturbed strata — Unconformable stratification — Fractures of strata — Polished surfaces — Faults — Appearance of repeated alternations produced by them — Origin of great faults.

Land has been raised, not the sea lowered. — It has been already stated that the aqueous rocks containing marine fossils extend over wide continental tracts, and are seen in mountain chains, rising to great heights above the level of the sea. Hence it follows, that what is now dry land was once under water. But if we admit this conclusion, we must imagine, either that there has been a general lowering of the waters of the ocean, or that the solid rocks, once covered by water, have been raised up bodily out of the sea, and have thus become dry land. The earlier geologists, finding themselves reduced to this alternative, embraced the former opinion, assuming that the ocean was originally universal, and had gradually sunk down to its actual level, so that the present islands and continents were left dry. It seemed to them far easier to conceive that the water had gone down, than that solid land had risen upwards into its present position. It was, however, impossible to invent any satisfactory hypothesis to explain the disappearance of so enormous a body of water throughout the globe, it being necessary to infer that the ocean had once stood at whatever height marine shells might be detected. It moreover appeared clear, as the science of Geology advanced, that certain spaces on the globe had been alternately sea, then land; then estuary, then sea again, and, lastly, once more habitable land, having remained in each of these states for considerable periods. In order to account for such phenomena, without admitting any movement of the land itself, we are required to imagine several retreats and returns of the ocean; and even then our theory applies merely to cases where the marine strata composing the dry land are horizontal, leaving unexplained those more common instances where strata are inclined, curved, or placed on their edges, and evidently not in the position in which they were first deposited.

Geologists, therefore, were at last compelled to have recourse to the other alternative, namely, the doctrine that the solid land has been repeatedly moved upwards or downwards, so as permanently to change its position relatively to the sea. There are several distinct grounds for preferring this conclusion. First, it will account equally for the position of those elevated masses of marine origin in which the stratification remains horizontal, and for those in which the strata are disturbed, broken, inclined, or vertical. Secondly, it is consistent with human experience that land should rise gradually in some places and be depressed in others. Such changes have actually occurred in our own days, and are now in progress, having been accompanied in some cases by violent convulsions, while in others they have proceeded so insensibly, as to have been ascertainable only by the most careful scientific observations, made at considerable intervals of time. On the other hand, there is no evidence from human experience of a lowering of the sea's level in any region, and the ocean cannot sink in one place without its level being depressed throughout the globe.

These preliminary remarks will prepare the reader to understand the great theoretical interest attached to all facts connected with the position of strata, whether horizontal or inclined, curved or vertical.

Now the first and most simple appearance is where a strata of marine origin occur above the level of the sea in horizontal position. Such are the strata which we meet with in the south of Sicily, filled with shells of the same species as now live in the Mediterranean. Some of these rocks rise to the height of more than 2000 feet above the sea. Other mountain masses might be mentioned composed of horizontal strata of high antiquity, which contain fossil remains of animals wholly dissimilar from any now known to exist. In the south of Sweden, for example, near Lake Wener, the beds of a deposit, called Transition or Silurian by geologists, occur in as level a position as if they had recently formed part of the delta of a great river, and been left dry on the retiring of the annual floods. Aqueous rocks of about the same age extend over the lake-district of North America, and exhibit in like manner a stratification nearly undisturbed. The Table Mountain at the Cape of Good Hope is another example of highly elevated yet perfectly horizontal strata, no less than 3500 feet in thickness, and consisting of sandstone of very ancient date.

Instead of imagining that such fossiliferous rocks were always at their present level, and that the sea was once high enough to cover them, we suppose them to have constituted the ancient bed of the ocean, and that they were gradually uplifted to their present height. This idea, however startling it may at first appear, is quite in accordance, as before stated, with the analogy of changes now going on in certain regions of the globe. Thus in parts of Sweden, and the shores and islands of the Gulf of Bothnia, proofs have been obtained that the land is experiencing, and has experienced for centuries, a slow upheaving movement. Playfair argued in favor of this opinion in 1802, and in 1807 Von Buch, after his travels in Scandinavia, announced his conviction that a rising of the land was in progress. Celsius and other Swedish writers had, a century before, declared their belief, that a gradual change had, for ages, been taking place in the relative level of land and sea. They attributed the change to a fall of the waters both of the ocean and the Baltic. This theory, however, has now been refuted by abundant evidence; for the alteration of relative level has neither been universal nor everywhere uniform in quantity, but has amounted, in some regions, to several feet in a century, in others to a few inches; while in the southernmost part of Sweden, or the province of Scania, there has been actually a loss instead of a gain of land, buildings having gradually sunk below the level of the sea.*

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* In the first three editions of my Principles of Geology, I expressed many doubts as to the validity of the alleged proofs of a gradual rise of land in Sweden; but after visiting

It appears from the observations of Mr. Darwin and others, that very extensive regions of the continent of South America have been undergoing slow and gradual upheaval, by which the level plains of Patagonia, covered with recent marine shells, and the Pampas of Buenos Ayres have been exposed.* On the other hand, the gradual sinking of the west coast of Greenland, for the space of more than 600 miles from north to south, during the last four centuries, has been established by the observations of a Danish naturalist, Dr. Pingel. And while these proofs of continental elevation and subsidence, by slow and insensible movements, have been recently brought to light, the evidence has been daily strengthened of continued changes of level effected by violent convulsions in countries where earthquakes are frequent. There the rocks are rent from time to time, and heaved up or thrown down several feet at once, and disturbed in such a manner, that the original position of strata may, in the course of centuries, be modified to any amount.

It has also been shown by Mr. Darwin, that, in

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that country, in 1834, I retracted these objections, and published a detailed statement of the observations which led me to alter my opinion in the Phil. Trans. 1835, Part I. See also the Principles, 4th and subsequent editions.

* See his Journal in Voyage of the Beagle.

those seas where circular coral islands abound, there is a slow and continued sinking of the submarine mountains on which the masses of coral are based; while in other areas of the South Sea, where coral is found above the sea level, and in inland situations, and where there are no circular or barrier reefs, the land is on the rise.*

It would require a volume to explain to the reader the various facts which establish the reality of these movements of land, whether of elevation or depression, whether accompanied by earthquakes or accomplished slowly and without local disturbance. Having treated fully of these subjects in the Principles of Geology, I shall assume, in the present work, that such changes are part of the actual course of nature; and when admitted, they will be found to afford a key to the interpretation of a variety of geological appearances, such as the elevation of horizontal, inclined, or disturbed marine strata, the superposition of freshwater to marine deposits, and many other phenomena, afterwards to be described. It will also appear, in the sequel, how much light the doctrine of a continued subsidence of land may throw on the manner in which a series of strata, formed in shallow water, may have accumulated to a great thickness. The excavation of valleys also, and other effects of *denudation*, of which I shall presently treat, can alone be understood when we duly appreciate the proofs, now on record, of the prolonged rising and sinking of land, throughout wide areas.

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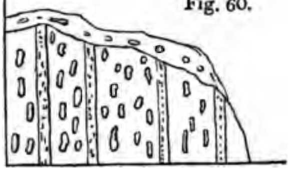
* Darwin, Proceedings of Geol. Soc. No. 51. p. 552., and his Journal in Voyage of the Beagle, vol. iii. p. 557.

To conclude this subject, I may remind the reader, that were we to embrace the doctrine which ascribes the elevated position of marine formations, and the depression of certain freshwater strata, to oscillations in the level of the waters instead of the land, we should be compelled to admit that the ocean has been sometimes everywhere much shallower than at present, and at others more than three miles deeper.

Inclined stratification. — The most unequivocal evidence of a change in the original position of strata is afforded by their standing up perpendicularly on their edges, which is by no means a rare phenomenon, especially in mountainous countries. Thus we find in Scotland, on the southern skirts of the Grampians, beds of pudding-stone alternating with thin layers of fine sand, all placed vertically to the horizon. When Saussure first observed certain conglomerates in a similar position in the Swiss Alps, he remarked that the pebbles, being for the

Fig. 60.



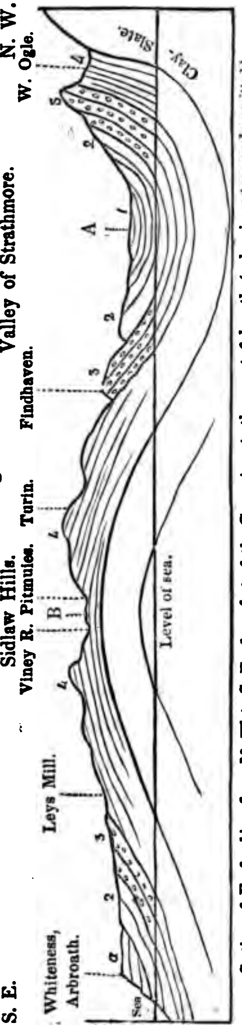
Vertical conglomerate and sandstone.

most part of an oval shape, had their longer axes parallel to the planes of stratification, (See Fig. 60.) From this he inferred, that such strata must, at first, have been horizontal, each oval pebble having originally settled at the bottom of the water, with its flatter side parallel to the horizon, for the same reason that an egg will not stand on either end if unsupported. Some few, indeed, of the rounded stones in a conglomerate may afford exceptions to the above rule, for the same reason that we see on a shingle beach an occasional oval or flat-sided pebble resting on its end or edge; some pebbles having been forced along the bottom and against each other, may have settled in this position.

Vertical strata, when they can be traced continuously upwards or downwards for some depth, are almost invariably seen to be parts of great curves, which may have a diameter of a few yards, or of several miles. I shall first describe two curves of considerable regularity, which occur in Forfarshire, extending over a country twenty miles in breadth, from the foot of the Grampians to the sea near Arbroath.

The mass of strata here shown may be nearly 2000 feet in thickness, consisting of red and white sandstone, and various colored shales, the beds being distinguishable into four principal groups, namely, No. 1. red marl or shale; No. 2. red

Fig. 61.

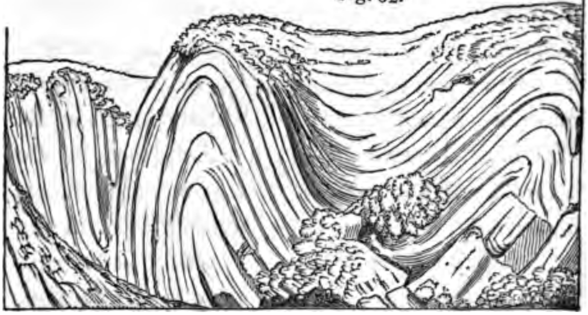


Section of Forfarshire, from N. W. to S. E., from foot of the Grampians to the sea at Arbroath, (volcanic or trap rocks omitted.)
Length of section twenty miles.

sandstone, used for building; No. 3. conglomerate: and No. 4., gray paving-stone, and tile-stone, with green and reddish shale, containing peculiar organic remains. A glance at the section will show that each of the formations 2, 3, 4, are repeated thrice at the surface, twice with a southerly and once with a northerly inclination or *dip*, and the beds in No. 1., which are nearly horizontal, are still brought up twice by a slight curvature to the surface, once on each side of A. Beginning at the northwest extremity, the tile-stones and conglomerates No. 4. and No. 3. are vertical, and they generally form a ridge parallel to the southern skirts of the Grampians. The superior strata Nos. 2. and 1. become less and less inclined on descending to the valley of Strathmore, where the strata, having a concave bend, are said by geologists to lie in a "trough" or "basin." Through the centre of this valley runs an imaginary line A, called technically a "synclinal line," where the beds, which are tilted in opposite directions, may be supposed to meet. It is most important for the observer to mark such lines, for he will perceive by the diagram, that in travelling from the north to the centre of the basin, he is always passing from older to newer beds; whereas, after crossing the line A, and pursuing his course in the same southerly direction, he is continually leaving the newer, and advancing upon older strata. All the deposits which he had before examined begin then to recur in reversed order, until he arrives at the central axis of the Sidlaw hills, where the strata are seen to form an arch or *saddle*, having an *anticlinal* line, B, in the centre. On passing this line, and continuing towards the S. E., the formations 4, 3, and 2, are again repeated, in the same relative order of superposition, but with a northerly dip. At Whiteness (see diagram) it will be seen that the inclined strata are covered by a newer deposit, *a*, in horizontal beds. These are composed of red conglomerate and sand, and are newer than any of the groups, 1, 2, 3, 4, before described, and rest *unconformably* upon strata of the sandstone group, No. 2.

An example of curved strata, in which the bends or convolutions of the rock are sharper and far more numerous within an equal space, has been well described by Sir James Hall.* It occurs near St. Abb's Head, on the east coast of Scotland, where the rocks consist principally of a bluish slate, having frequently a ripple-marked surface. The undulations of the beds reach from the top to the bottom of cliffs from 200 to 300 feet in height, and there are sixteen distinct bendings in the course of about six miles, the curvatures being alternately concave and convex upwards.

Fig. 62.



Curved strata of slate near St. Abb's Head, Berwickshire. (Sir J. Hall.)

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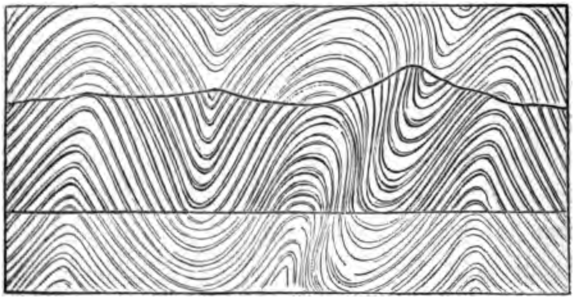
* Edin. Trans. vol. vii. pl. 3.

An experiment was made by Sir James Hall, with a view of illustrating the manner in which such strata, assuming them to have been originally horizontal, may have been forced into their present position. A set of layers of clay were placed under a weight, and their opposite ends pressed towards each other with such force as to cause them to approach more nearly together. On the removal of the weight, the layers of clay were found to be curved and folded, so as to bear a miniature resemblance to the strata in the cliffs. We must, however, bear in mind, that in the natural section or sea-cliff we only see the foldings imperfectly, one part being invisible beneath the sea, and the other, or upper portion, being supposed to have been carried away by *denudation*, or that action of water which will be explained in the next chapter. The dark lines in the accompanying plan (Fig. 63.), represent what is actually

Fig. 63.



seen of the strata in part of the line of cliff alluded to; the fainter lines, that portion which is concealed beneath the sea level, as also that which is supposed to have once existed above the present surface.

We may still more easily illustrate the effects which a lateral thrust might produce on flexible strata, by placing several pieces of differently colored cloths upon a table, and when they are spread out horizontally, cover them with a book. Then apply other books to each end, and force them towards each other. The folding of the cloths will exactly imitate those of the bent strata. (See Fig. 64.)

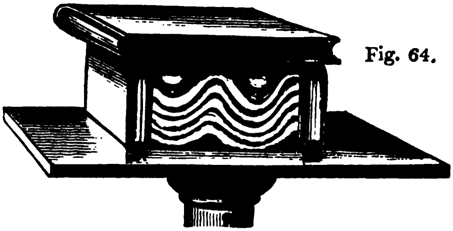


Fig. 64.

Whether the analogous flexures in stratified rocks have really been due to similar sideway movements is a question of considerable difficulty. It will appear when the volcanic and granitic rocks are described, that some of them have, when melted, been injected forcibly into fissures, while others, already in a solid state, have been protruded upwards through the incumbent crust of the earth, by which a great displacement of flexible strata must have been caused.

But we also know by the study of regions liable to earthquakes, that there are causes at work in the interior of the earth capable of producing a sinking in of the ground, sometimes very local, but sometimes extending over a wide area. The frequent repetition, or continuance throughout long periods, of such downward movements seems to imply the formation and renewal of cavities at a certain depth below the surface, whether by the removal of matter by volcanos and hot springs, or by the contraction of argillaceous rocks by heat and pressure, or any other combination of circumstances. Whatever conjectures we may indulge respecting the causes, it is certain that pliable beds may, in consequence of unequal degrees of subsidence, become folded to any amount, and have all the appearance of having been compressed suddenly by a lateral thrust.

The "Creeps," as they are called in coal mines, afford an excellent illustration of this fact. First, it may be stated generally, that the excavation of coal at a considerable depth causes the mass of overlying strata to sink down bodily, even when props are left to support the roof of the mine. "In Yorkshire," says Mr. Buddle, "three distinct subsidences were perceptible at the surface, after the clearing out of three seams of coal below, and innumerable vertical cracks were caused in the incumbent mass of sandstone and shale, which thus settled down."* The exact amount of depression in these cases can only be accurately measured where water accumulates on the surface, or a railway traverses a coal-field.

When a bed of coal is worked out, pillars or rectangular masses of coal are left at intervals as props to support the roof, and protect the colliers. Thus in Fig. 65., representing a section at Wallsend, Newcastle, the galleries which have been excavated are represented by the white spaces *a b*, while the adjoining dark portions are parts of the original coal-seam left as props, beds of sandy clay or shale constituting the floor of the mine. When the props have been reduced in size, they are pressed down by the weight of overlying rocks no less than 630 feet thick, upon the shale below, which is thereby squeezed and forced up into the open spaces.

Now it might have been expected, that instead of the floor rising up, the ceiling would sink down, and this effect, called a "Thrust," does, in fact, take place where the pavement is more solid than the roof. But it usually happens, in coal-mines, that the roof is composed of sandstone or other materials more unyielding than the foundation, which often consists of clay or shale. Even where

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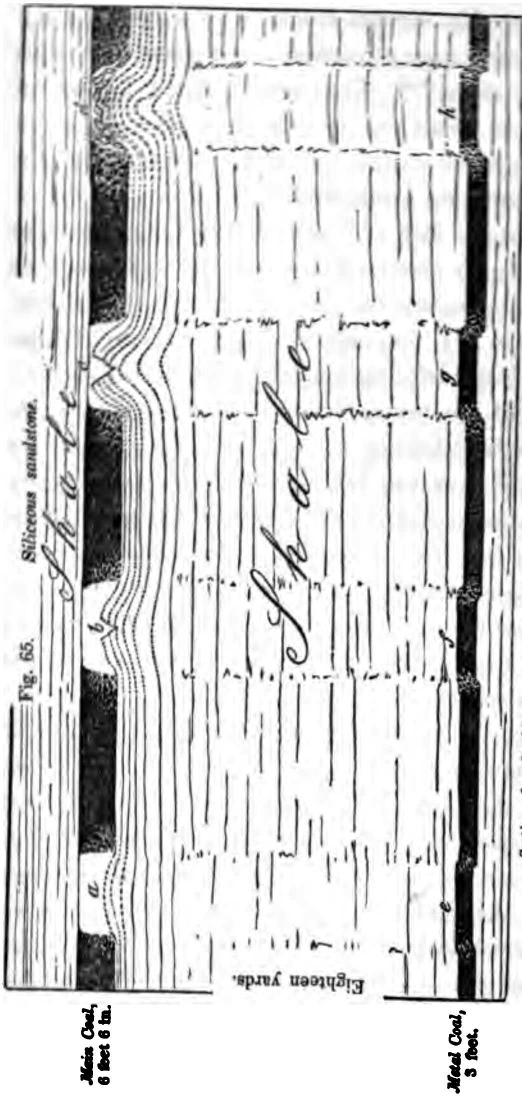
* Proceedings of Geol. Soc. vol. iii. p. 148.

Fig. 65.



Section of carboniferous strata, at Walls-end, Newcastle, showing "Creeps." (J. Buddle, Esq.)
Horizontal length of section 174 feet. The upper seam, or main coal, here worked out, was 630 feet below the surface.

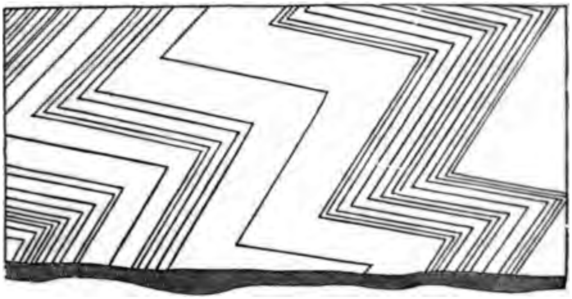
the argillaceous substrata are hard at first, they soon become softened and reduced to a plastic state when exposed to the contact of air and water in the floor of a mine.

The first symptom of a "creep," says Mr. Buddle, is a slight curvature at the bottom of each gallery, as at *a*, Fig. 65. : then the pavement continuing to rise, begins to open with a longitudinal crack, as at *b* : then the points of the fractured ridge reach the roof, as at *c*; and, lastly, the upraised beds close up the whole gallery, and the broken portions of the ridge are reunited and flattened at the top, exhibiting the flexure seen at *d*. Meanwhile the coal in the props has become crushed and cracked by pressure. It is also found, that below the creeps *a*, *b*, *c*, *d*, an inferior stratum, called the "metal coal," which is three feet thick, has been fractured at the points, *e*, *f*, *g*, *h*, and has risen, so as to prove that the upward movement, caused by the working out of the "main coal," has been propagated through a thickness of 54 feet of argillaceous beds, which intervene between the two coal seams. This same displacement has also been traced downwards more than 150 feet below the metal coal, but it grows continually less and less until it becomes imperceptible.

No part of the process above described is more deserving of our notice than the slowness with which the change in the arrangement of the beds is brought about. Days, months, or even years, will sometimes elapse between the first bending of the pavement and the time of its reaching the roof. Where the movement has been most rapid, the curvature of the beds is most regular, and the reunion of the fractured ends most complete; whereas the signs of displacement or violence are greatest in those creeps which have required months or years for their entire accomplishment. Hence we may conclude that similar changes may have been wrought on a larger scale in the earth's crust by partial and gradual subsidences, especially where the ground has been undermined throughout long periods of time; and we must be on our guard against inferring sudden violence, simply because the distortion of the beds is excessive.

Between the layers of shale, accompanying coal, we sometimes see the leaves of fossil ferns spread out as regularly as dried plants between sheets of paper in the herbarium of a botanist. These fern-leaves, or fronds, must have rested horizontally on soft mud, when first deposited. If, therefore, they and the layers of shale are now inclined, or standing on end, it is obviously the effect of subsequent derangement. The proof becomes, if possible, still more striking when these strata, including vegetable remains, are curved again and again, and even folded into the form of the letter Z, so that the same continuous layer of coal is cut through several times in the same perpendicular shaft. Thus, in the coal-field near Mons, in Belgium, these zigzag

Fig. 66.



Zigzag flexures of coal near Mons.

bendings are repeated four or five times, in the manner represented in Fig. 66., the black lines representing seams of coal.*

Dip and Strike. — In the above remarks, several technical terms have been used, such as *dip*, the *unconformable position* of strata, and the *anticlinal* and *synclinal* lines, which, as well as the *strike* of the beds, I shall now explain. If a stratum or bed of rock, instead of being quite level, be inclined to one side, it is said to *dip*; the point of the compass to which it is inclined is called the *point of dip*, and the degree of deviation from a level or horizontal line is called *the amount of dip*,

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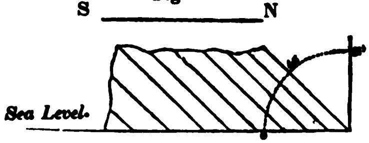
* See plan by M. Chevalier, Burat's D'Aubuisson, tom. ii. p. 334.

Fig. 67.



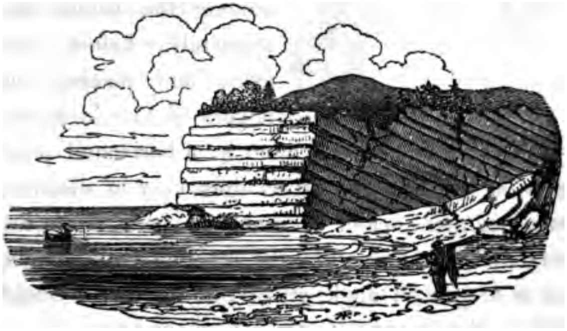
or *the angle of dip.* Thus, in the annexed diagram (Fig. 67.), a series of strata are inclined, and they dip to the north at an angle of forty-five degrees. The *strike*, or *line of bearing*, is the prolongation or extension of the strata in a direction *at right angles* to the dip; and hence it is sometimes called the *direction* of the strata. Thus, in the above instance of strata dipping to the north, their strike must necessarily be east and west. We have borrowed the word from the German geologists, *streichen* signifying to extend, to have a certain direction. Dip and strike may be aptly illustrated by a row of houses running east and west, the long ridge of the roof representing the strike of the stratum of slates, which dip on one side to the north, and on the other to the south.

A stratum which is horizontal, or quite level in all directions, has neither dip nor strike.

It is always important for the geologist, who is endeavouring to comprehend the structure of a country, to learn how the beds dip in every part of the district; but it requires some practice to avoid being occasionally deceived, both as to the point of dip and the amount of it.

If the upper surface of a hard stony stratum be uncovered, whether artificially in a quarry, or by the waves at the foot of a cliff, it is easy to determine towards what point of the compass the slope is steepest, or in what direction water would flow, if poured upon it. This is the true dip. But the edges of highly inclined strata may give rise to perfectly horizontal lines in the face of a vertical cliff, if the observer see the strata in the line of their strike, the dip being inwards from the face of the cliff. If, however, we come to a break in the cliff, which exhibits a section exactly at right angles to the line of the strike, we are then able to ascertain the true dip. In the annexed drawing (Fig. 68.), we may suppose a headland, one side of which faces to the north, where the beds would appear perfectly horizontal, to a person in the boat; while in the other side facing the

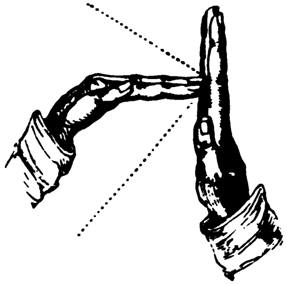
Fig. 68.



Apparent horizontality of inclined strata.

west, the true dip would be seen by the person on shore to be at an angle of 40°. If, therefore, our observations are confined to a vertical precipice facing in one direction, we must endeavour to find a ledge or portion of the plane of one of the beds projecting beyond the others, in order to ascertain the true dip.

Fig. 69.



It is rarely important to determine the angle of inclination with such minuteness as to require the aid of the instrument called a clinometer. We may measure the angle within a few degrees by standing exactly opposite to a cliff where the true dip is exhibited, holding the hands immediately before the eyes, and placing the fingers of one in a perpendicular, and of the other in a horizontal position, as in Fig. 69. It is thus easy to discover whether the lines of the inclined beds bisect the angle of 90°, formed by the meeting of the hands, so as to give an angle of 45°, or whether it would divide the space into two equal or unequal portions. The upper dotted line may express a stratum dipping to the north; but should the beds dip precisely to the opposite point of the compass as in the lower dotted line, it will be seen that the amount of inclination may still be measured by the hands with equal facility.

It has been already seen, in describing the curved strata on the east coast of Scotland, in Forfarshire and Berwickshire, that a series of concave and convex bendings are occasionally repeated several times. These usually form part of a series of parallel waves of strata, which are prolonged in the same direction throughout a considerable extent of country. Thus, for example, in the Swiss Jura, that lofty chain of mountains has been proved to consist of many parallel ridges, with intervening longitudinal valleys, as in Fig. 70., the ridges being formed by curved fossiliferous strata, of which the nature and dip are occasionally displayed in deep transverse gorges, called "cluses," caused by fractures at right angles to the direction of the chain.* Now let us suppose these ridges and parallel valleys to run north and south, we should then say that the *strike* of the beds is north and south, and the *dip* east and west. A line drawn along the summit of the ridges A, B would be an anticlinal line, and one following the bottom of the adjoining valleys a synclinal line. It will be observed that some of these ridges, A, B, are unbroken on the summit, whereas one of them,

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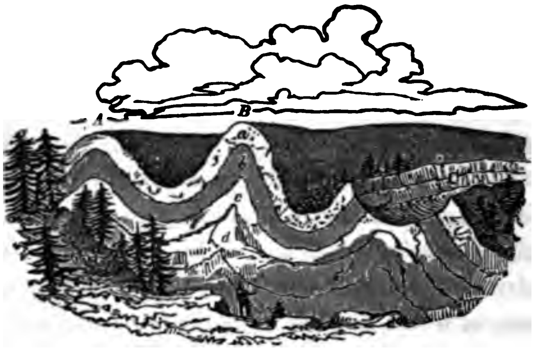
* See M. Thurmann's work, "Essai sur les Soulèvemens Jurassiques du Porrentruy, Paris, 1832," with whom I examined part of these mountains in 1835.

C, has been fractured along the line of strike, and a portion of it carried away by denudation, so that the edges of the beds in the formations *a*, *b*, *c*, come out to the day, or, as the miners say,

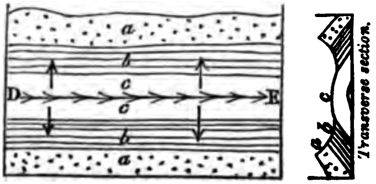
Fig. 70.



Section illustrating the structure of the Swiss Jura.

crop out, on the sides of a valley. The ground plan of such a denuded ridge as C, as given in a geological map, may be expressed by the diagram Fig. 71., and the cross section of the same by Fig. 72. The line D E, Fig. 71., is the anti-

Fig. 71. Fig. 72.



Ground plan of the denuded ridge C, fig. 70.

clinal line, on each side of which the dip is in opposite directions, as expressed by the arrows. The emergence of strata at the surface is called by miners their *outcrop* or *basset*.

If, instead of being folded into parallel ridges, the beds form a boss or dome-shaped protuberance, and if we suppose the summit of the dome carried off, the ground plan would exhibit the edges of the strata forming a succession of circles, or ellipses, around a common centre. These circles are the lines of strike, and the dip being always at right angles is inclined in the course of the circuit to every point of the compass, constituting what is termed a qua-qua-versal dip, — that is, turning each way.

There are endless variations in the figures described by the basset-edges of the strata, according to the different inclination of the beds, and the mode in which they happen to have been denuded. One of the simplest rules with which every geologist should be acquainted, relates to the V-like form of the beds as they crop out in an ordinary valley. First, if the strata be horizontal, the V-like form will be also on a level, and the newest strata will appear at the greatest heights.

Secondly, if the beds be inclined and intersected by a valley sloping in the same direction, and the dip of the beds be less steep than the slope of the valley, then the V's, as they are often termed by miners, will point upwards (see Fig. 73.), those formed by the newer beds appearing in a superior position, and extending highest up the valley, as A is seen above B.

Thirdly, if the dip of the beds be steeper than the slope of the valley, then the V's will point downwards (see Fig. 74.), and those formed of the older beds will now appear uppermost, as B appears above A.

Fourthly, in every case where the strata dip in a contrary direction to the slope of the valley, whatever be the angle of inclination, the newer beds will appear the highest, as in the first and second cases. This is shown by the drawing (Fig. 75.), which exhibits strata rising at an angle of 20°, and crossed by a valley, which declines in an opposite direction at 20°.*

These rules may often be of great practical utility; for the different degrees of dip occurring in the two cases represented in figures 73. and 74. may occasionally be encountered in following the same line of flexure at points a few miles distant from each other. A miner unacquainted with the rule, who had first explored the valley (Fig. 73.), may have sunk a vertical shaft below the coal

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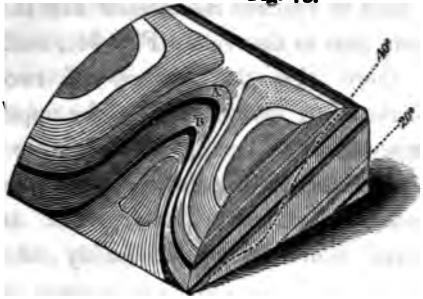
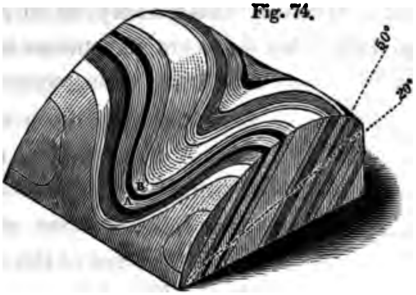
* I am indebted to the kindness of T. Sqpwith, Esq., for three models constructed by him, which I have copied in the above diagrams.

Fig. 73.



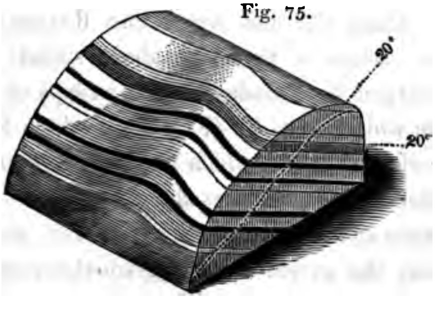
Slope of valley 40°, dip of strata 20°.

Fig. 74.



Slope of valley 20°, dip of strata 50°

Fig. 75.

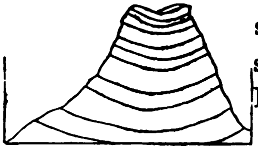


Slope of valley 20°, dip of strata 20°, in opposite directions.

seam A, until he reached the inferior bed B. He might then pass to the valley Fig. 74., and, discovering there also the outcrop of two coal seams, might begin his workings in the uppermost in the expectation of coming down to the other bed A, which would be observed cropping out lower down the valley. But a glance at the section will demonstrate the futility of such hopes.

In the majority of cases, an anticlinal axis forms a ridge, and a synclinal axis a valley, as in A, B, Fig. 61. p. 103.; but there are exceptions to this rule, the beds sometimes sloping inwards from either side of a mountain, as in Fig. 76.

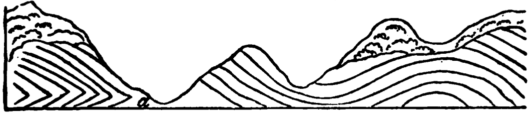
Fig. 76.



On following one of the anticlinal ridges of the Jura, before mentioned, A, B, C, Fig. 70., we often discover longitudinal cracks and sometimes large fissures along the line where the flexure was greatest. Some of these, as above stated, have been enlarged by denudation into valleys of considerable width, as at C. (Fig. 70.), which follow the line of strike, and which we may suppose to have been hollowed out at the time when these rocks were still beneath the level of the sea, or perhaps at the period of their gradual emergence from beneath the waters. The existence of such cracks at the point of the sharpest bending of solid strata of limestone, such as that constituting the formation *a* (Fig. 70), is precisely what we should have expected; but the occasional want of all similar signs of fracture, even where the strain has been equally great, is not always easy to explain. We must imagine that many strata of limestone, chert, and other rocks which are now brittle, were pliant when bent into their present position. They may have owed their flexibility in part to the fluids which they contained in their minute pores, as before described (p. 76.), and in part to the permeation of sea water while they were yet submerged.

At the western extremity of the Pyrenees, great curvatures of the strata are seen in the sea cliffs, where the rocks consist of marl, grit, and chert. At certain points, as at *a* (Fig. 77.), some of the bendings of the flinty chert are so sharp, that specimens might be broken off, well fitted to serve as ridge-tiles on the roof of a house. Although this chert could not have been brittle as now,

Fig. 77.

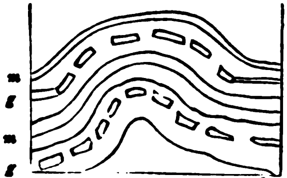


Strata of chert, grit, and marl, near St. Jean de Luz.

when first folded into this shape, it presents, nevertheless, here and there at the points of greatest flexure small cracks, which show that it was solid, and not wholly incapable of breaking at the period of its displacement. The numerous rents alluded to are not empty, but filled with calcedony and quartz.

Between San Caterina and Castrogiovanni, in Sicily, bent and undulating gypseous marls occur, with here and there thin beds of solid gypsum interstratified. Sometimes these solid layers have been broken into detached fragments, still preserving their sharp edges, (*g g*, Fig. 78.), while the continuity of the more pliable and ductile marls, *m m*, has not been interrupted.

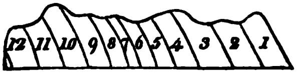
Fig. 78.



g. gypsum. *m*. marl.

I shall conclude my remarks on bent strata by stating, that, in mountainous regions like the Alps, it is often difficult for an experienced geologist to determine correctly the relative age of beds by superposition, so often have the strata been folded back upon themselves, the upper parts of the curve having been removed by denudation. Thus, if we met with the strata seen in the section Fig. 79., we should naturally suppose that there were twelve distinct beds, or sets

Fig. 79.



of beds, No. 1. being the youngest, and No. 12. the oldest of the series. But this section may, perhaps, exhibit merely six beds, which have been folded in the manner seen in Fig. 80., so that each of them are twice repeated, the position of one half being reversed, and part of No. 1., originally the uppermost, having now become the lowest of the series. These phenomena are often observable on a magnificent scale in certain regions in Switzerland, where there are precipices from 2000 to 3000 feet in perpendicular height. In the Iselten Alp, in the valley of the Lutschine, between Unterseen and Grindelwald, curves of calcareous shale are seen from 1000 to 1500 feet in height, in which the beds sometimes plunge down vertically for a depth of 1000 feet and more, before they bend round again. There are many flexures not inferior in

Fig. 80.

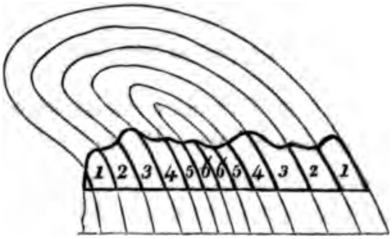
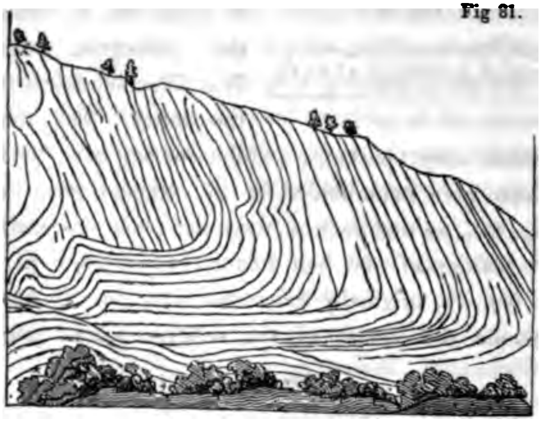


Fig 81.



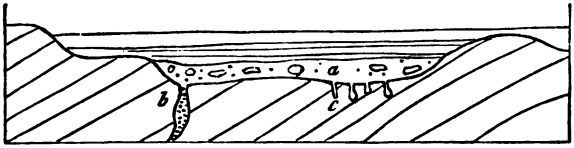
Curved strata of the Iselten Alp.

dimensions in the Pyrenees, as those near Gavarnie, at the base of Mont Perdu.

Unconformable stratification. — Strata are said to be unconformable, when one series is so placed over another, that the planes of the superior repose on the edges of the inferior (see Fig. 82.). In this case it is evident that a period had elapsed between the production of the two sets of strata, and that, during this interval, the inferior series had been tilted and disturbed. Afterwards the upper series was thrown down in horizontal strata upon it. If these superior beds are also inclined, it is plain that the lower strata have been twice displaced; first, when they were themselves brought into an inclined position, and a second time when the superior beds were thrown out of the horizontal line.

It often happens, that, in the interval between the deposition of two sets of unconformable strata, the inferior rock has been denuded, and sometimes drilled by perforating shells. Thus, for example, at Autreppe and Gusigny, near Mons, beds of ancient stone, commonly called transition limestone, highly inclined, and often bent, are covered with horizontal strata of greenish and whitish marls of the Cretaceous formation, which will be described in a future chapter. The lowest and therefore the oldest bed of the horizontal series is usually the sand and conglomerate, *a*, in which are rounded fragments of stone, from an inch to two feet in diameter. These fragments have often adhering shells attached to them, and have been bored by perforating mollusca. The solid surface of the inferior limestone has also been bored, so as to exhibit cylindrical and pear-shaped cavities, as at *c*, the work of saxicavous mollusca; and many rents, as at *b*, which descend

Fig. 82.



Junction of unconformable strata near Mons, in Belgium.

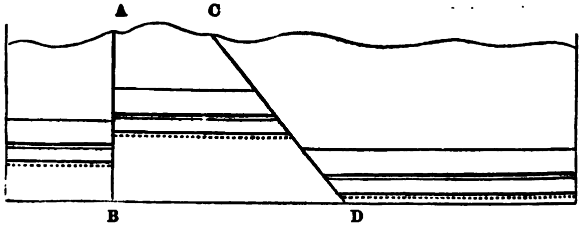
several feet or yards into the limestone, have been filled with sand and shells, similar to those in the stratum *a*.

Fractures of the strata and faults. — Numerous rents may often be seen in rocks which appear to have been simply broken, the separated parts remaining in the same places; but we often find a fissure, several inches or yards wide, intervening between the disunited portions. These fissures are usually filled with fine earth and sand, or with angular fragments of stone, evidently derived from the fracture of the contiguous rocks.

The face of each wall of the fissure is often beautifully polished, as if glazed, and not unfrequently striated or scored with parallel furrows and ridges, such as would be produced by the continued rubbing together of surfaces of unequal hardness. These polished surfaces are called by miners " slickensides." It is supposed that the lines of the striæ indicate the direction in which the rocks were moved. During one of the late minor earthquakes in Chili, the brick walls of a building were rent vertically in several places, and made to vibrate for several minutes during each shock, after which they remained uninjured, and without any opening, although the line of each crack was still visible. When all movement had ceased, there were seen on the floor of the house, at the bottom of each rent, small heaps of fine brickdust, evidently produced by trituration.

It is not uncommon to find the mass of rock, on one side of a fissure, thrown up above or down below the mass with which it was once in contact on the other side. This mode of displacement is called a shift, slip, or fault. "The miner," says Playfair, describing a fault, "is often perplexed, in his subterraneous journey, by a derangement in the strata, which changes at once all those lines and bearings which had hitherto directed his course. When his mine reaches a certain plane, which is sometimes perpendicular, as in A B, Fig. 83., sometimes oblique to the horizon (as in C D, ibid.), he finds the beds of rock broken asunder, those on the one side of the plane having changed their place, by sliding in a particular direction along the face of the others. In this motion they have sometimes preserved their parallelism, as in Fig. 83., so that the strata on each side of the faults, A B, C D, con-

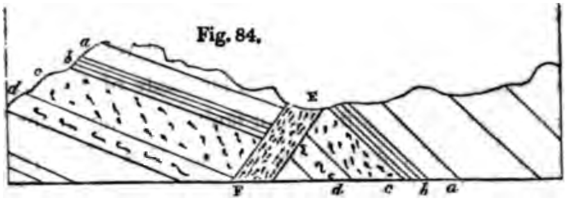
Fig. 83.



Faults. A B *perpendicular*, C D *oblique to the horizon.*

tinue parallel to one another; in other cases, the strata on each side are inclined, as in *a*, *b*, *c*, *d*, (Fig. 84.), though their identity is still to be recognised by their possessing the same thickness, and the same internal characters." *

Fig. 84.



E F, *fault or fissure filled with rubbish, on each side of which the shifted strata are not parallel.*

In Coalbrook Dale, says Mr. Prestwich†, deposits of sandstone, shale, and coal, several thousand feet thick, and occupying an area of many miles, have been shivered into fragments, and the broken remnants have been placed in very discordant positions, often at levels differing several hundred feet from each other. The sides of the faults, when perpendicular, are commonly separated several yards, but are sometimes as much as 50 yards asunder, the interval being filled with broken *débris* of the strata. In following the course of the same fault it is sometimes found to produce, in different places, very unequal changes of level, the amount of shift being in one place 300, and in another 700 feet, which arises, in some cases, from the union of two or more faults. In other words, the disjointed strata have in certain districts been subjected to renewed movements, which they have not suffered elsewhere.

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* Playfair, Illust. of Hutt. Theory, § 42.

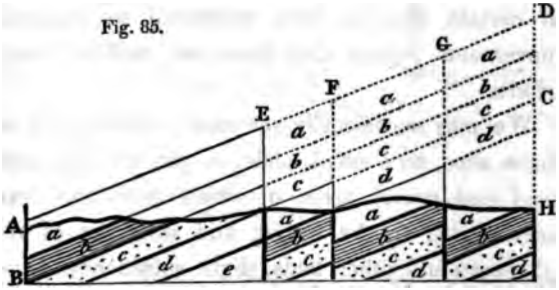
† Geol. Trans. second series, vol. v. p. 452.

We may occasionally see exact counterparts of these slips, on a small scale, in pits of fine loose sand and gravel, many of which have doubtless been caused by the drying and shrinking of argillaceous and other beds, slight subsidences having taken place from failure of support. Sometimes, however, even these small slips may have been produced during earthquakes; for land has been moved, and its level, relatively to the sea, considerably altered, within the period when much of the alluvial sand and gravel now covering the surface of continents was deposited.

I have already stated that a geologist must be on his guard, in a region of disturbed strata, against inferring repeated alternations of rocks, when, in fact, the same strata, once continuous, have been bent round so as to recur in the same section, and with the same dip. A similar mistake has often been occasioned by a series of faults.

If, for example, the dark line A H (Fig. 85.) represent the surface of a country on which the strata *a b c* frequently crop out, an observer, who is proceeding from H to A, might at first imagine that at every step he was approaching new strata, whereas the repetition of the same beds has been

Fig. 85.



Apparent alternations of strata caused by vertical faults.

caused by vertical faults, or downthrows. Thus, suppose the original mass, A, B, C, D, to have been a set of uniformly inclined strata, and that the different masses under E F, F G, and G D, sank down successively, so as to leave vacant the spaces marked in the diagram by dotted lines, and to occupy those marked by the continuous lines, then let denudation take place along the line A H, so that the protruding and triangular masses indicated by the fainter lines, are swept away, — a miner, who has not discovered the faults, finding the mass *a*, which we will suppose to be a bed of coal four times repeated, might hope to find four beds, workable to an indefinite depth, but first on arriving at the fault G he is stopped suddenly in his workings, upon reaching the strata of sandstone *c*, or on arriving at the line of fault

F he comes partly upon the shale *b*, and partly on the sandstone *c*, and on reaching E he is again stopped by a wall composed of the rock *d*.

The very different levels at which the separated parts of the same strata are found on the different sides of the fissure, in some faults, is truly astonishing. One of the most celebrated in England is that called the "ninety-fathom dike," in the coal-field of Newcastle. This name has been given to it, because the same beds are ninety fathoms lower on the northern than they are on the southern side. The fissure has been filled by a body of sand, which is now in the state of sandstone, and is called the dike, which is sometimes very narrow, but in other places more than twenty yards wide.* The walls of the fissure are scored by grooves, such as would have been produced if the broken ends of the rock had been rubbed along the plane of the fault.† In the Tynedale and Craven faults, in the north of England, the vertical displacement is still greater, and has extended in a horizontal direction for a distance of thirty miles or more. Some geologists consider it necessary to imagine that the upward or downward movement in these cases was accomplished at a single stroke, and not by a series of sudden but interrupted movements.

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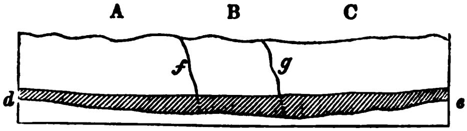
* Conybeare and Phillips, Outlines, &c. p. 376.

† Phillips, Geology, Lardner's Cyclop. p. 41.

This idea appears to have been derived from a notion that the grooved walls have merely been rubbed in one direction. But this is so far from being a constant phenomenon in faults, that it has often been objected to the received theory respecting those polished surfaces called "slickensides," that the striæ are not always parallel, but often curved and irregular. It has, moreover, been remarked, that not only the walls of the fissure or fault, but its earthy contents, sometimes present the same polished and striated faces. Now these facts seem to indicate partial changes in the direction of the movement, and some slidings subsequent to the first filling up of the fissure. Suppose the mass of rock A, B, C, to overlie an extensive chasm *d e*, formed at the depth of several miles, whether by the gradual contraction in bulk of a mass of strata, baked by a moderate heat, or by the subtraction of matter by volcanic action, or any other cause. Now if this region be convulsed by earthquakes, the fissures *f g*, and others at right angles to them, may sever the mass B from A and from C, so that it may move freely,

Fig. 86.



and begin to sink into the chasm. A fracture may be conceived so clean and perfect as to allow it to subside at once to the bottom of the subterranean cavity; but it is far more probable that the sinking will be effected at successive periods during different earthquakes, the mass always continuing to slide in the same direction along the planes of the fissures *f g*, and the edges of the falling mass being continually more broken and triturated at each convulsion. If, as is not improbable, the circumstances which have caused the failure of support continue in operation, it may happen that when the mass B has filled the cavity first formed, its foundations will again give way under it, so that it will fall again in the same direction. But, if the direction should change, the fact could not be discovered by observing the slickensides, because the last scoring would efface the lines of previous friction. In the present state of our ignorance of the causes of subsidence, an hypothesis which can explain the great amount of displacement in some faults, on sound mechanical principles, by a succession of movements, is far preferable to any theory which assumes each fault to have been accomplished by a single upcast or downthrow of several thousand feet. For we know that there are operations now in progress, at great depths in the interior of the earth, by which both large and small tracts of ground are made to rise above and sink below their former level, some slowly and insensibly, others suddenly and by starts, a few feet or yards at a time; whereas there are no grounds for believing, that, during the last 3000 years at least, any regions have been either upheaved or depressed, at a single stroke, to the amount of several hundred, much less several thousand feet.

CHAPTER. VI.

DENUDATION.

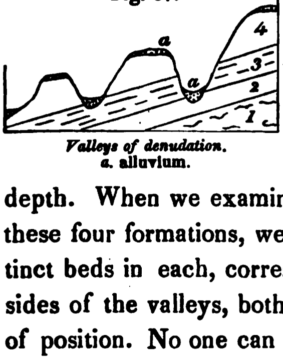
Denudation defined — Its amount equal to the entire mass of stratified deposits in the earth's crust — Horizontal sandstone denuded in Ross-shire — Levelled surface of countries in which great faults occur — Coalbrook Dale — Denuding power of the ocean during the emergence of land — Origin of valleys — Inland sea-cliffs and terraces in the Morea and Sicily — Limestone pillars at St. Mihiel, in France — in Canada — in the Bermudas — Obliteration of cliffs.

DENUDATION, which has been occasionally spoken of in the preceding chapters, is the removal of solid matter by running water, whether by a river or marine current, and the consequent laying bare of some inferior rock. Geologists have perhaps been seldom in the habit of reflecting that this operation has exerted an influence on the structure of the earth's crust as universal and important as sedimentary deposition itself; for denudation is the inseparable accompaniment of the production of all new strata of mechanical origin. The formation of every new deposit by the transport of sediment and pebbles necessarily implies that there has been, somewhere else, a grinding down of rock into rounded fragments, sand, or mud, equal in quantity to the new strata. All deposition, therefore, except in the case of a shower of volcanic ashes, is the sign of superficial waste going on contemporaneously, and to an equal amount, elsewhere. The gain at one point is no more than sufficient to balance the loss at some other. Here a lake has grown shallower, there a ravine has been deepened. The bed of the sea has in one region been raised by the accumulation of new matter, in another its depth has been augmented by the abstraction of an equal quantity.

When we see a stone building, we know that somewhere, far or near, a quarry has been opened. The courses of stone in the building may be compared to successive strata, the quarry to a ravine or valley which has suffered denudation. As the strata, like the courses of hewn stone, have been laid one upon another gradually, so the excavation both of the valley and quarry have been gradual. To pursue the comparison still further, the superficial heaps of mud, sand, and gravel usually called alluvium, may be likened to the rubbish of a quarry which has been rejected as useless by the workmen, or has fallen upon the road between the quarry and the building, so as to lie scattered at random over the ground.

If, then, the entire mass of stratified deposits in the earth's crust is at once the monument and measure of the denudation which has taken place, on how stupendous a scale ought we to find the signs of this removal of transported materials in past ages! Accordingly, there are different classes of phenomena, which attest in a most striking manner the vast spaces left vacant by the erosive power of water. I may allude, first, to those valleys on both sides of which the same strata are seen following each other in the same order, and having the same mineral composition and fossil contents. We may observe, for example, several formations, as Nos. 1, 2, 3, 4, in the accompanying diagram (Fig. 87.); No. 1. conglomerate, No. 2. clay, No. 3. grit, and No. 4. limestone, each repeated in a series of hills separated by valleys varying in depth. When we examine the subordinate parts of these four formations, we find, in like manner, distinct beds in each, corresponding, on the opposite sides of the valleys, both in composition and order of position. No one can doubt that the strata were originally continuous, and that some cause has swept away the portions which once connected the whole series. A torrent on the side of a mountain produces similar interruptions; and when we make artificial cuts in lowering roads, we expose, in like

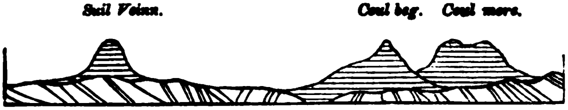
Fig. 87.



Valleys of denudation.
a. alluvium.

manner, corresponding beds on either side. But in nature, these appearances occur in mountains several thousand feet high, and separated by intervals of many miles or leagues in extent, of which a grand exemplification is described by Dr. MacCulloch, on the northwestern coast of Ross-shire, in Scotland.*

Fig. 88.



Denudation of red sandstone on northwest coast of Ross-shire. (MacCulloch.)

The fundamental rock of that country is gneiss, in disturbed strata, on which beds of nearly horizontal red sandstone rest unconformably. The latter are often very thin, forming mere flags, with their surface distinctly ripple-marked. They end abruptly on the declivities of many insulated mountains, which rise up at once to the height of about 2000 feet above the gneiss of the surrounding plain or table land, and to an average elevation of about 3000 feet above the sea, which all their summits generally attain. The base of gneiss varies in height, so that the lower portions of the sandstone occupy different levels, and the thickness of the mass is various, sometimes exceeding 3000 feet. It is impossible to compare these scattered and detached portions without imagining that the whole country has once been covered with a great body of sandstone, and that masses from 1000 to more than 3000 feet in thickness have been removed.

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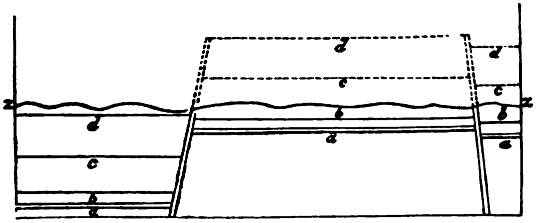
* Western Islands, vol. ii. p. 93. pl. 31. fig. 4.

But perhaps the most convincing evidence of denudation on a magnificent scale is derived from the levelled surface of many districts, in which large faults occur. I have already shown, in Fig. 85. p. 132., and in Fig. 89., how angular and protruding masses of rock might naturally have been looked for on the surface immediately above great faults, although in fact they rarely exist. This phenomenon may be well studied in those districts where coal has been extensively worked, for there the former relation of the beds which have shifted their position may be determined with great accuracy. Thus in the coal field of Ashby de la Zouch, in Leicestershire (see Fig. 89.), a fault occurs, on one side of which the coal beds *a b c d*

Fig. 89.



Faults and denuded coal strata, Ashby de la Zouch. (Mammat.)

rise to the height of 500 feet above the corresponding beds on the other side. But the uplifted strata do not stand up 500 feet above the general surface; on the contrary, the outline of the country, as expressed by the line *x x*, is uniform and unbroken, and the mass indicated by the dotted outline must have been washed away.* There are proofs of this kind in some level countries, where dense masses of strata have been cleared away from areas several hundred square miles in extent.

In the Newcastle coal district it is ascertained that faults occur in which the upward or downward movement could not have been less than 140 fathoms, which, had they affected equally the configuration of the surface to that amount, would produce mountains with precipitous escarpments nearly 1000 feet high, or chasms of the like depth; yet is the actual level of the country absolutely uniform, affording no trace whatever of subterranean movements.†

The ground from which these materials have been removed is usually overspread with heaps of sand and gravel, formed out of the ruins of the very rocks which have disappeared. Thus, in the districts above referred to, they consist of rounded and angular fragments of hard sandstone, limestone, and ironstone, with a small quantity of the more destructible shale, and even rounded pieces of coal.

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* See Mammat's Geological Facts, &c. p. 90. and plate.

† Conybeare's Report to Brit. Assoc. 1832, p. 381.

Allusion has been already made to the shattered state and discordant position of the carboniferous strata in Coalbrook Dale (p. 130.). The collier cannot proceed three or four yards without meeting with small slips, and from time to time he encounters faults of considerable magnitude, which have thrown the rocks up or down several hundred feet. Yet the superficial inequalities to which these dislocated masses originally gave rise are no longer discernible, and the comparative flatness of the existing surface can only be explained, as Mr. Prestwich has observed, by supposing the fractured portions to have been removed by water. It is also clear that strata of red sandstone, more than 1000 feet thick, which once covered the coal, in the same region, have been carried away from large areas. That water has, in this case, been the denuding agent, we may infer from the fact, that the rocks have yielded according to their different degrees of hardness; the hard trap of the Wrekin, for example, and other hills, having resisted more than the softer shale and sandstone, so as now to stand out in bold relief.*

Origin of valleys. — It is very generally admitted, that the greater number of valleys are chiefly or entirely due to the excavating power of water, but many different theories have been entertained respecting the manner in which the force of moving water has been brought to bear upon the land. Some geologists, being at a loss to conceive any combination of known causes capable of giving rise to effects of such magnitude, have imagined a deluge, or succession of deluges, caused by the sudden upheaval of mountain chains, to have rolled with resistless violence over the land, after it had acquired its present elevation above the sea. But many gratuitous assumptions are involved in this hypothesis; and even if we were disposed to grant the instantaneous upthrow from the ocean of lofty chains, and a series of enormous waves, as a consequence of each convulsion, we can by no means account for the observed phenomena. On the other hand, it has now been ascertained, that the rising and sinking of extensive portions of the earth's crust, whether insensibly or by a repetition of sudden shocks, is part of the actual course of nature, and we may easily comprehend how the land may have been exposed during these movements to abrasion by the waves of the sea. In the same manner as a mountain mass may (in the course of ages) be formed by sedimentary deposition, layer after layer, so masses equally voluminous may in time waste away by inches, as for example, if beds of incoherent materials are raised slowly in an open sea where a strong current prevails. It is well known that some of these oceanic currents have a breadth of 200 miles, and that they sometimes run for a thousand miles or more in one direction, retaining a considerable velocity even at the depth of several hundred feet. Under these circumstances, the flowing waters may have power to clear away each stratum of incoherent materials as it rises and approaches the surface, where the waves exert the greatest force; and in this manner a voluminous deposit may be entirely swept away, so that, in the absence of faults, no evidence may remain of the denuding operation. It is clear, therefore, that the signs of waste will usually be least obvious where the destruction has been most complete, the annihilation having proceeded so far, that no ruins are left of the dilapidated rocks: nevertheless, we may always appeal to one striking proof of the vast extent of denudation in times past, namely, the existence before alluded to in all parts of the earth's crust of strata of mechanical origin, many thousand feet thick (see page 137.).

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* Prestwich, Geol. Trans. second series, vol. v. pp. 452. 473.

In regard to valleys, it may be observed, that denudation, which has often had a levelling influence on countries of shattered and disturbed strata, (see Fig. 85. p. 132. and Fig. 89. p. 141.) is the chief cause of superficial inequalities in regions of horizontal stratification. The general outline of these regions is that of flat and level platforms, interrupted by valleys often of considerable depth, and ramifying in various directions. These dry hollows may once have formed bays and channels between islands, and the steepest slope on the sides of each valley may have been a sea-cliff, which was undermined for ages, as the land emerged gradually from the deep. We may suppose the position and course of each valley to have been originally determined by differences in the hardness of the rocks, and by rents and joints which usually occur even in horizontal strata. In mountain chains, such as the Jura before described, (see Fig. 70. p. 118.) we perceive at once that the principal valleys have not been due to aqueous excavation, but to those mechanical movements which have bent the rocks into their present form. Yet even in the Jura there are many valleys, such as C, (Fig. 70.) which have been hollowed out by water; and it may be stated, that in every part of the globe the unevenness of the surface of the land has been due to the combined influence of subterranean movements and denudation.

I may now recapitulate a few of the conclusions to which we have arrived: first, all the mechanical strata have been accumulated gradually, and the concomitant denudation has been no less gradual: secondly, the dry land consists in great part of strata formed originally at the bottom of the sea, and has been made to emerge and attain its present height by a force acting from beneath : thirdly, no combination of causes has yet been conceived so capable of producing extensive and gradual denudation, as the action of the waves and currents of the ocean upon land slowly rising out of the deep.

Now, if we embrace these conclusions, we shall naturally be led to look everywhere for marks of the former residence of the sea upon the land, especially near the coasts from which the last retreat of the waters took place, and it will be found that such signs are not wanting. Thus, in the Morea, no less than three, or even four, ranges of what were once sea-cliffs are well preserved. These have been described, by MM. Boblaye and Virlet, as rising one above the other at different distances from the actual shore, the summit of the highest and oldest occasionally exceeding 1000 feet in elevation. At the base of each there is usually a terrace, which is in some places a few yards, in others above 300 yards wide, so that we are conducted from the high land of the interior to the sea by a succession of great steps. These inland cliffs are most perfect, and most exactly resemble those now washed by the waves of the Mediterranean, where they are formed of calcareous rock, especially if the rock be a hard crystalline marble. The following are the points of correspondence observed between the ancient coast lines and the borders of the present sea:— 1. A range of vertical precipices, with a terrace at their base. 2. A weathered state of the surface of the naked rock, such as the spray of the sea produces. 3. A line of littoral caverns at the foot of the cliffs. 4. A consolidated beach or breccia with occasional marine shells, found at the base of the cliffs, or in the caves. 5. Lithodomous perforations.

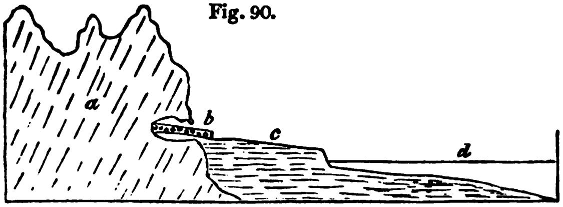
In regard to the first of these, it would be superfluous to dwell on the evidence afforded of the undermining power of waves and currents by perpendicular precipices. The littoral caves, also, will be familiar to those who have had opportunities of observing the manner in which the waves of the sea, when they beat against rocks, have power to scoop out caverns. As to the breccia, it is composed of pieces of limestone and rolled fragments of thick solid shells, such as *Strombus* and *Spondylus*, all bound together by a crystalline calcareous cement. Similar aggregations are now forming on the modern beaches of Greece, and in caverns on the sea-side; and they are only distinguishable in character from those of more ancient date, by including many pieces of pottery. In regard to the *lithodomi* above alluded to, these bivalve mollusks are well known to have the power of excavating holes in the hardest limestones, the size of the cavity keeping pace with the growth of the shell. When living they require to be always covered by salt water, but similar pear-shaped hollows, containing the dead shells of these creatures, are found at different heights on the face of the inlands cliffs above mentioned. Thus, for example, they have been observed near Modon and Navarino on cliffs in the interior 125 feet high above the Mediterranean. As to the weathered surface of the calcareous rocks, all limestones are known to suffer chemical decomposition when moistened by the spray of the salt water, and are corroded still more deeply at points lower down where they are just reached by the breakers. By this action the stone acquires a wrinkled and furrowed outline, and very near the sea it becomes rough and branching, as if covered with corals. Such effects are traced not only on the present shore but at the base of the ancient cliffs far in the interior. Lastly, it remains only to speak of the terraces, which extend with a gentle slope from the base of almost all the inland cliffs, and are for the most part narrow where the rock is hard, but sometimes half a mile or more in breadth where it is soft. They are the effects of the encroachment of the ancient sea upon the shore at those levels at which the land remained for a long time stationary. The justness of this view is apparent on examining the shape of the modern shore wherever the sea is advancing upon the land, and removing annually small portions of undermined rock. By this agency a submarine platform is produced on which we may walk for some distance from the beach in shallow water, the increase of depth being very gradual, until we reach a point where the bottom plunges down suddenly. This platform is widened with more or less rapidity according to the hardness of the rocks, and when upraised it constitutes an inland terrace.

But the four principal lines of cliffs observed in the Morea do not imply, as some have imagined, four great eras of sudden upheaval; they simply indicate the intermittance of the upheaving force. Had the rise of the land been continuous and uninterrupted, there would have been no one prominent line of cliff; for every portion of the surface having been, in its turn, and for an equal period of time, a sea-shore, would have presented a nearly similar aspect. But if pauses occur in the process of upheaval, the waves and currents have time to sap, throw down, and clear away considerable masses of rock, and to shape out at certain levels lofty ranges of cliffs with broad terraces at their base.

There are some levelled spaces, however, both ancient and modern, in the Morea, which are not due to denudation, although resembling in outline the terraces above described. They may be called Terraces of Deposition, since they have resulted from the gain of land upon the sea where rivers and torrents have produced deltas. If the sedimentary matter has filled up a bay or gulf surrounded by steep mountains, a flat plain is formed skirting the inland precipices; and if these deposits are upraised, they form a feature in the landscape very similar to the areas of denudaton before described.

In the island of Sicily are many inland cliffs like those of the Morea; as for example, near Palermo, where a precipice is seen consisting of limestone at the base of which are numerous caves.

Fig. 90.



a. Monte Grifone. *b.* Cave of San Ciro.*
c. Plain of Palermo, in which are Newer Pliocene strata of limestone and sand. *d.* Bay of Palermo.

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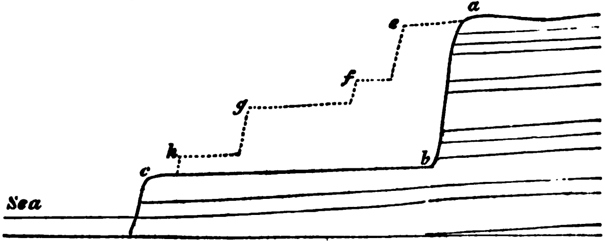
* Section given by Dr. Christie, Edin. New Phil. Journ. No. xxiii., called by mistake the Cave of Mardolce, by the late M. Hoffmann. See account by Mr. S. P. Pratt, F. G. S. Proceedings of Geol. Soc. No. 32. 1833.

One of these called San Ciro, about 2 miles distant from Palermo, is about 20 feet high, 10 wide, and 180 above the sea. Within it is found an ancient beach (*b.* Fig. 90.), formed of pebbles of various rocks, many of which must have come from places far remote. Broken pieces of coral and shell, especially of oysters and pectens, are seen intermingled with the pebbles. Immediately above the level of this beach, *serpulæ* are still found adhering to the face of the rock, and the limestone is perforated by *lithodomi*. Within the grotto, also, at the same level, similar perforations occur; and so numerous are the holes, that the rock is compared by Hoffmann to a target pierced by musket balls. But in order to expose to view these marks of boring-shells in the interior of the cave, it was necessary first to remove a mass of breccia, which consisted of numerous fragments of rock, and an immense quantity of bones of the mammoth, hippopotamus, and other quadrupeds, imbedded in a dark brown calcareous marl. Many of the bones were rolled as if partially subjected to the action of the waves. Below this breccia, which is about twenty feet thick, was found a bed of sand filled with sea-shells of recent species; and underneath the sand, again, is the secondary limestone of Monte Grifone. The state of the surface of the limestone in the cave above the level of the marine sand is very different from that below it. *Aobve*, the rock is jagged and uneven, as is usual in the roofs and sides of limestone caverns; *below*, the surface is smooth and polished, as if by the attrition of the waves.

The platform indicated at *c*, Fig. 90., is formed by a tertiary deposit containing marine shells almost of all living species, and it affords an illustration of the terrace of deposition, or the last of the two kinds before mentioned (p. 151.).

There are also numerous instances in Sicily of terraces of denudation. One of these occurs on the east coast to the north of Syracuse, and the same is resumed to the south beyond the town of Noto, where it forms a continuous and lofty precipice *a*, *b*, facing towards the sea, and constituting the abrupt termination of a calcareous formation, which extends in horizontal strata far inland. This precipice varies in height from 500 to 700 feet, and between its base and the sea is an inferior platform *c*, *b*, consisting of similar white limestone. All the beds dip towards the sea, but are usually

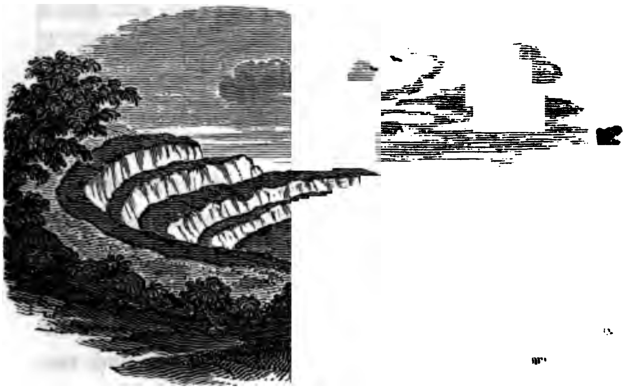
Fig. 91.



inclined at a very slight angle: they are seen to extend uninterruptedly from the base of the escarpment into the platform, showing distinctly that the lofty cliff was not produced by a fault or vertical shift of the beds, but by the removal of a considerable mass of rock. Hence we may conclude that the sea, which is now undermining the cliffs of the Sicilian coast, reached at some former period the base of the precipice *a*, *b*, at which time the surface of the terrace *c*, *b*, must have been covered by the Mediterranean. There was a pause, therefore, in the upward movement, when the waves of the sea had time to carve out the platform *c*, *b*; but there may have been many other stationary periods of minor duration. Suppose, for example, that a series of escarpments *e*, *f*, *g*, *h*, once existed, and that the sea, during a long interval free from subterranean movements, advances along the line *c*, *b*, all preceding cliffs must have been swept away one after the other, and reduced to the single precipice *a*, *b*.

That such a series of smaller cliffs, as those represented at *e*, *f*, *g*, *h*, Fig. 91., did really once exist at intermediate heights in place of the single precipice *a*, *b*, is rendered highly probable by the fact, that in certain bays and inland valleys opening towards the east coast of Sicily, and not far from the section given in Fig. 91., the solid limestone is shaped out into a great succession of ledges, separated from each other by small vertical cliffs. These are sometimes so numerous, one above the other, that where there is a bend at the head of a valley, they produce an effect singularly resembling the seats of a Roman amphitheatre. A good example of this configuration occurs near the town of Melilli, as seen in the annexed view (Fig. 92.). In the south of the island, near Spaccaforno, Scicli, and Modica, precipitous rocks of white limestone, ascending to the height of 500 feet, have been carved out into similar forms.

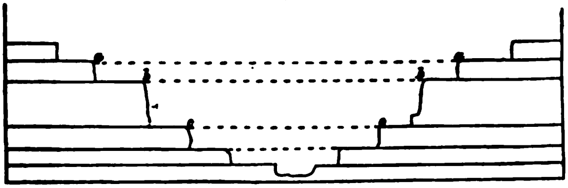
Fig. 92.



Valley called Gozzo degli Martiri, below Melilli, Val di Noto.

This appearance of a range of marble seats circling round the head of a valley, or of great flights of steps descending from the top to the bottom, on the opposite sides of a gorge, may be accounted for, as already hinted, by supposing the sea to have stood successively at many different levels, as at *a*, *a*, *c*, *c*, *b*, *b*, in the accompanying fig. 93. But the causes of the gradual contraction of the valley from above downwards may still be matter of speculation. Such contraction may be due to the greater force exerted by the waves when the land at its first emergence was smaller in quantity, and more exposed to denudation in an open sea; whereas the wear and tear of the rocks might diminish in proportion as this action became confined within bays or channels closed in on two or three sides. Or, secondly, the separate movements of elevation may have followed each other more rapidly as the land continued to rise, so that the times of those pauses, during which the greatest denudation was accomplished at certain levels, were always growing shorter. It should be remarked, that the cliffs and small terraces are rarely found on the opposite sides of the Sicilian valleys at heights so precisely

Fig. 93.



answering to each other as those given in Fig. 93., and this might have been expected, to whichever of the two hypotheses above explained we incline; for, according to the direction of the prevailing winds and currents, the waves may beat with unequal force on different parts of the shore, so that while no impression is made on one side of a bay, the sea may encroach so far on the other as to unite several smaller cliffs into one.

Before quitting the subject of ancient sea-cliffs, carved out of limestone, I shall mention the range of precipitous rocks, composed of a white marble of the Oolitic period, which may be seen near the northern gate of St. Mihiel in France. They are situated on the right bank of the Meuse, at a distance of 200 miles from the nearest sea, and they present on the precipice facing the river three or four horizontal grooves, one above the other, precisely resembling those which are scooped out by the undermining waves. The summits of several of these masses are detached from the adjoining hill, in which case the grooves pass all round them, facing towards all points of the compass, as if they had once formed rocky islets near the shore.*

Captain Bayfield, in his survey of the Gulf of

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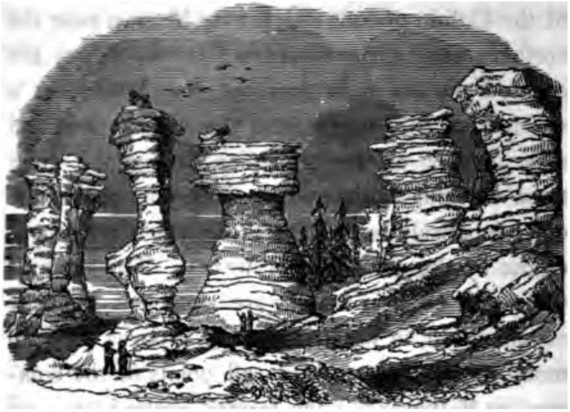
* I was directed by M. Deshayes to this spot, which I visited in June, 1833.

St. Lawrence, discovered in several places, especially in the Mingan islands, a counterpart of the inland cliffs of St. Mihiel, and traced a succession of shingle beaches, one above the other, which agreed in their level with some of the principal grooves scooped out of the limestone pillars. These beaches consisted of calcareous shingle, with shells of recent species, the furthest from the shore being sixty feet above the level of the highest tides. In addition to the drawings of the pillars called the flower-pots, which he has published,* I have been favored with other views of rocks on the same coast, drawn by Lieut. A. Bowen, R. N. (See Fig. 94.)

Fig. 94.



Limestone columns in Niapisca Island, in the Gulf of St. Lawrence. Height of the second column on the left, 60 feet.

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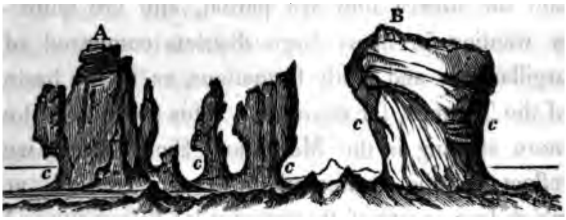
* See Trans. of Geol. Soc., second series, vol. v. plate v.

In the North-American beaches above mentioned rounded fragments of limestone have been found perforated by *lithodomi;* and holes drilled by the same mollusks have been detected in the columnar rocks or "flower-pots," showing that there has been no great amount of atmospheric decomposition on the surface, or the cavities alluded to would have disappeared.

We have an opportunity of seeing in the Bermuda islands the manner in which the waves of the Atlantic have worn, and are now wearing out, deep smooth hollows on every side of projecting masses of hard limestone. In the annexed drawing, communicated to me by Lieut. Nelson, the excavations *c*, *c*, *c*, have been scooped out by the waves in a stone of very modern date, which, although extremely hard, is full of recent corals and shells, some of which retain their color.

Fig. 95.



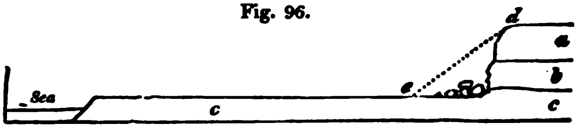
The North Rocks, Bermuda, lying outside the great coral reef.
A. 16 feet high, and B. 12 feet. *c. c.* Hollows worn by the sea.

When the forms of these horizontal grooves, of which the surface is sometimes smooth and almost polished, and the roofs of which often overhang to the extent of five feet or more, have been carefully studied by geologists, they will serve to testify the former action of the waves at innumerable points far in the interior of the continents. But we must learn to distinguish the indentations due to the original action of the sea, and those caused by subsequent chemical decomposition of calcareous rocks, to which they are liable in the atmosphere.

It may be asked why, if the doctrines above expounded are true, there are not inland cliffs and sea-beaches everywhere? whereas, even in Sicily and the Morea they are partial, and are entirely wanting in many large districts composed of argillaceous and sandy formations, as in the basin of the Thames, for example. This absence is the more striking in the Morea and Sicily, when we reflect on the comparatively recent period at which large parts of those countries have emerged from the deep. The modern date of that event is shown either by shells of recent species found in raised beaches, or imbedded in calcareous and argillaceous formations. Yet, notwithstanding the comparative shortness of the time since these strata emerged from the deep, and the fresh aspect of some of the inland cliffs above described, it is difficult, in general, when we pass beyond the limits of the solid limestone, to detect any signs of the beating of the waves on ancient shores. That the soft marly and sandy strata were upheaved at the same time, and by the same intermittent movements as the adjoining calcareous rocks, cannot be doubted. To understand in such cases the rarity of the traces of ancient shores, we must observe how soon all recent marks of the same kind are obscured or entirely effaced on any point of our own coast, where, in consequence of the altered state of the tides and currents, the sea has receded for a few centuries. We see the cliffs crumble down in a few years, and if they have consisted of sand or clay, they are soon reduced to a gentle slope. If there were shells on the beach they decompose, and their materials are soon washed away, after which the sand and shingle may resemble any other alluviums scattered over the interior.

The features of an ancient shore may be concealed by the growth of trees and shrubs, or by a covering of blown sand, a good example of which occurs a few miles west from Dax, near Bourdeaux, in the South of France. About twelve miles inland, a steep bank may be traced running in a direction nearly northeast and southwest, or parallel to the contiguous coast. This sudden fall of about fifty feet conducts us from the higher platform of the Landes to a lower plain which extends to the sea. The outline of the ground might suggest to every geologist the opinion

Fig. 96.



Section of Inland Cliff at Abesse, near Dax.

a. Sand of the Landes. *b.* Limestone. *c.* Clay.

that the bank in question was once a sea-cliff, when the whole country stood at a lower level. But this can no longer be regarded as matter of conjecture. In making excavations in 1830, for the foundation of a building at Abesse, a quantity of loose sand, which formed the slope *d e*, was removed; and a perpendicular cliff, about fifty feet in height, which had hitherto been protected from the agency of the elements, was exposed. At the bottom appeared the limestone *b*, containing tertiary shells and corals, immediately below it the clay (*c*), and above it the usual tertiary sand (*a*), of the department of the Landes. At the base of the precipice are seen large partially rounded masses of rock, evidently detached from the stratum *b*. The face of the limestone is hollowed out and weathered into such forms as are seen in the calcareous cliffs of the adjoining coast, especially at Biaritz, near Bayonne. It is evident that, when the country was at a somewhat lower level, the sea advanced along the surface of the argillaceous stratum *c*, which, from its yielding nature, favored the waste by allowing the more solid superincumbent stone *b* to be readily undermined. Afterwards, when the country had been elevated, part of the sand, *a*, fell down, or was drifted by the winds, so as to form the talus, *d e*, which masked the inland cliff until it was artificially laid open to view.

When we are considering the various causes which, in the course of ages, may efface the characters of an ancient sea-coast, earthquakes must not be forgotten. During violent shocks, steep and overhanging cliffs are often thrown down and become a heap of ruins. Sometimes unequal movements of upheaval or depression entirely destroy the horizontality of that base-line which constitutes the chief peculiarity of an ancient sea-cliff.

CHAPTER VII.

ALLUVIUM.

Alluvium described — Due to complicated causes — Of various ages, as shown in Auvergne — How distinguished from rocks *in situ* — River-terraces — Parallel roads of Glen Roy — Various theories respecting their origin.

BETWEEN the superficial covering of vegetable mould and the subjacent rock, there usually intervenes in every district a deposit of loose gravel, sand, and mud, to which the name of alluvium has been applied. The term is derived from *alluvio*, an inundation, or *alluo*, to wash, because the pebbles and sand commonly resemble those of a river's bed or the mud and gravel spread over low lands by a flood.

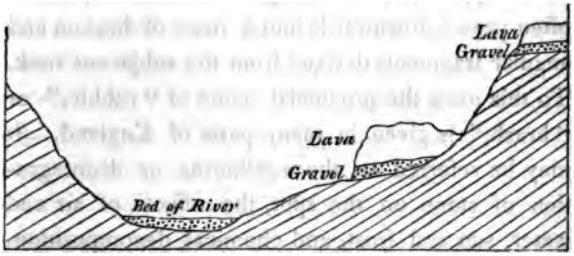
A partial covering of such alluvium is found alike in all climates, from the equatorial to the polar regions; but in the higher latitudes of Europe and North America it assumes a distinct character, being very frequently devoid of stratification, and containing huge fragments of rock, some angular and others rounded, which have been transported to great distances from their parent mountains. When it presents itself in this form, it has been called "diluvium," "drift," or the "boulder formation"; and its probable connexion with the agency of floating ice and glaciers will be treated of more particularly in the tenth and eleventh chapters.

After what was said of denudation, the student will not be surprised to hear that loose gravel and sand are often met with at various points both on the summits and sides of mountains, and on the low grounds bordering rivers. For during the gradual emergence of land from the sea, or the changes which may take place in the physical geography of a district after it has been laid dry, any point may either have been a sunken reef, or the bottom of a bay or estuary, or a sea-shore, or the bed of a river. For this reason it would be unreasonable to hope that we should ever be able to account for all the alluvial phenomena of each particular country, seeing that the causes of their origin are so complicated. Moreover, the last operations of water have a tendency to disturb and confound together all preëxisting alluviums. Hence we are always in danger of regarding as the work of a single era, and the effect of one cause, what has in reality been the result of a variety of distinct agents, during a long succession of geological epochs. Much useful instruction may therefore be gained from the examination of a country like Auvergne, where the superficial gravel of very different eras happens to have been preserved by sheets of lava, which were poured out one after the other at periods when the denudation, and probably the upheaval, of rocks were in progress. That region had already acquired in some degree its present configuration before any volcanos were in activity, and before any igneous matter was superimposed upon the granitic and fossiliferous formations. The pebbles therefore in the older gravels are exclusively constituted of granite and other aboriginal rocks; and afterwards, when volcanic vents burst forth into eruption, those earlier alluviums were covered by streams of lava, which protected them from intermixture with gravel of subsequent date. In the course of ages, a new system of valleys was excavated, so that the rivers ran at lower levels than those at which the first alluviums and sheets of lava were formed. When therefore fresh eruptions gave rise to new lava, the melted matter was poured out over lower grounds; and the gravel of these plains differed from the first or upland alluvium, by containing in it rounded fragments of various volcanic rocks.

The annexed drawing will explain the different heights at which beds of lava and gravel, each distinct from the other in composition and age, are observed, some on the flat tops of hills, 700 or

800 feet high, others on the slope of the same hills, and the newest of all in the channel of the

Fig. 97.



Lavas of Auvergne resting on alluviums of different ages.

existing river where there is usually gravel alone, but in some cases a narrow thread of solid lava occupying together with the river the bottom of the valley. The streams in this country are still undermining their banks and grinding down into pebbles or sand columns of basalt and fragments of granite and gneiss; but the older alluviums, in which the bones of extinct quadrupeds have been detected, are prevented from being mingled with the gravel of recent date by the cappings of lava before mentioned. But for the accidental interference, therefore, of this peculiar cause, all the alluviums might have passed so insensibly the one into the other, that those formed at the remotest era might have appeared of the same date as the newest, and the whole formation might have been regarded by some geologists as the result of one sudden and violent catastrophe.

In almost every country, the alluvium consists in its upper part of transported materials, but it often passes downwards into a mass of broken and angular fragments derived from the subjacent rock. To this mass the provincial name of "rubble," or "brash," is given in many parts of England. It may be referred to the weathering or disintegration of stone on the spot, the effects of air and water, sun and frost, and chemical decomposition. Sometimes the vibrations and undulations of earthquakes may have had power, at some former era, to shatter a surface previously rent and weathered. Thus in Calabria, subterranean movements have been known to throw up into the air the slabs of a stone pavement*; and Mr. Darwin mentions, that in the Island of Quiriquina, in Chili, some narrow ridges of hard primary slate, which is there the fundamental rock, were as completely shivered by the vibrations of the great earthquake of February, 1835, as if they had been blasted by gunpowder. The effect was merely superficial, and had caused fresh fractures and displacement of the soil, the slate below remaining solid and uninjured.†

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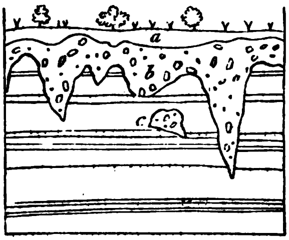
* See Princ. of Geol., Index, "Calabria."

† Darwin's Journal of Travels in S. America, &c. 1832 to 1836, in Voyage of H. M. S. Beagle, p. 370.

The inferior surface of alluvial deposits is often very irregular, conforming to all the inequalities of the fundamental rocks (Fig. 98.). Occasionally, a small mass, as at *c*, appears detached, and as if included in the subjacent formation. Such isolated portions are usually sections of winding subterranean hollows filled up with alluvium. They may have been the courses of springs or subterranean streamlets, which have flowed through and enlarged natural rents; or, when on a small scale and in soft strata, they may be spaces which the roots of large trees have once occupied, gravel and sand having been introduced after their decay.

Fig. 98.



a. vegetable soil. *b.* alluvium.
c. mass of same, apparently detached.

It is not so easy as may at first appear to draw a clear line of distinction between the *fixed* rocks, or regular strata (rocks *in situ* or *in place*), and alluvium. If the bed of a torrent or river be dried up, we call the gravel, sand, and mud, left in their channels, or whatever, during floods, they may have scattered over the neighbouring plains, *alluvium.* The very same materials carried into a lake, where they become sorted by water and arranged in more distinct layers, are termed regular strata.

In the same manner we may often contrast the gravel, sand, and broken shells, strewed along the path of a rapid marine current, with a deposit formed contemporaneously by the discharge of similar materials, year after year, into a deeper and more tranquil part of the sea. In such cases, when we detect marine shells or other organic remains entombed in the strata, which enable us to determine their age and mode of origin, we regard them as part of the regular series of fossiliferous formations, whereas if there are no fossils, we have frequently no power of separating them from the general mass of superficial alluvium.

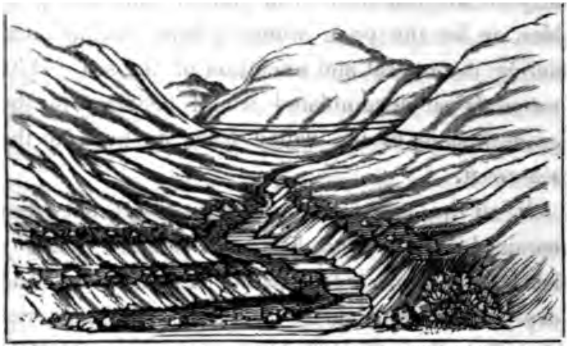
The usual rarity of organic remains in beds of loose gravel and sand is partly owing to the rapid and turbid water in which they were formed having been in a condition unfavorable to the habitation of aquatic beings, and partly to their porous nature, which, by allowing the free percolation of rain water, has promoted the decomposition and removal of organic matter.

It has long been a matter of common observation that rivers in general are now cutting their channels through alluvial deposits of greater depth and extent than could ever have been formed by the present streams. Now this may be explained, if we suppose a wide submarine area to have been raised by a gradual and uniform motion and made to emerge. In this case, friths, bays, estuaries, and the straits between islands, will dry up slowly, and, during their conversion into valleys, every part may in its turn be a sea-shore, and may be strewed over with littoral sand and pebbles, or be the point where a delta accumulated during the retreat and exclusion of the sea. The materials so accumulated would conform to the general slope of the valley from its head to the sea-coast.

If, on the other hand, a country has not been upraised equally, but has been subject to many local convulsions accompanied by upheaval and depression, its drainage will be repeatedly deranged, and rivers will be made to forsake their ancient channels from time to time. During these wanderings, a large space may become covered with fluviatile detritus, through which we may find all the modern streams cutting their channels.

River terraces. — We often observe, at a short distance from the present bed of a river, a steep cliff a few feet or yards high, and on a level with the top of it a flat terrace, corresponding in appearance to the alluvial plain which immediately borders the river. This terrace is again bounded by another cliff, above which a second terrace sometimes occurs; and in this manner two or three ranges of cliffs and terraces are occasionally seen on one or both sides of the stream, the number varying, but those on the opposite sides often corresponding in height.

Fig. 99.



River Terraces and Parallel Roads.

These terraces are seldom continuous for great distances, and their surface is not horizontal, but slopes downwards, with an inclination similar to that of the river or valley. They are readily explained if we adopt the hypothesis before suggested, of a gradual rise of the land; for, while this is going on new, deposits, before submerged, are exposed to denudation, and in these the rivers shape out their beds. If the sea be deep where the valley terminates, every addition made to the height of the land by upheaval will rapidly augment the fall of the water, and at the same time its cutting power; and if, as is most probable, the upheaving movement be intermittent, long pauses will occur, during which the stream will have time to encroach upon one of its banks, so as to clear away and flatten a large space. This operation being afterwards repeated at lower levels, there will be several successive cliffs and terraces.

Parallel roads.—The parallel roads, or shelves as they have been called, of Glen Roy and other valleys in Scotland, are distinct both in character and origin from the terraces above described; for they have no slope towards the sea like the channel of a river, nor are they the effect of denudation. Glen Roy is situated in the western Highlands, about ten miles north of Fort William, near the western end of the great glen of Scotland, or Caledonian Canal, and near the foot of the highest of the Grampians, Ben Nevis. Throughout its whole length, a distance of more than ten miles, two, and in its lower part three, parallel roads or shelves are traced along the steep sides of the mountains, as represented in Fig. 99., each maintaining a perfect horizontality, and continuing at exactly the same level on the opposite sides of the glen. Seen at a distance, they appear like ledges or roads, cut artificially out of the sides of the hills; but when we are upon them we can scarcely recognise their existence, so uneven is their surface, and so covered with boulders. They are from ten to sixty feet broad, and merely differ from the side of the mountain by being somewhat less steep.

On closer inspection, we find that these terraces are stratified in the ordinary manner of alluvial or littoral deposits, as may be seen at those points where ravines have been excavated by torrents. The parallel shelves, therefore, have not been caused by denudation, but by the deposition of detritus, precisely similar to that which is dispersed in smaller quantities over the declivities of the hills above. These hills consist of clay-slate, mica-schist, and granite, which rocks have been worn away and laid bare at a few points only, in a line just above the parallel roads. The highest of these roads is about 1250 feet above the level of the sea, the next about 200 feet lower than the uppermost, and the third still lower by about 50 feet. It is only this last, or the lowest of the three, which is continued throughout Glen Spean, a large valley with which Glen Roy unites. As the shelves are always at the same height above the sea, they become continually more elevated above the river in proportion as we descend each valley; and they at length terminate very abruptly, without any obvious cause, either in the shape of the ground, or any change in the composition or hardness of the rocks. I should exceed the limits of this work, were I to attempt to give a full description of all the geographical circumstances attending these remarkable terraces, or to discuss the ingenious theories which have been severally proposed to account for them by Dr. MacCulloch, Sir T. D. Lauder, Mr. Darwin, and Mr. Agassiz. There is one point, however, on which all are agreed, namely, that these shelves are ancient beaches, or littoral formations accumulated round the edges of one or more sheets of water which once stood at the level, first of the highest shelf, and successively at the height of the two others. It is well known, that wherever a lake or fiord exists, surrounded by steep mountains subject to disintegration by frost or the action of torrents, some loose matter is washed down annually, especially during the melting of snow, and a check is given to the descent of this detritus at the point where it reaches the waters of the lake. The waves then spread out the materials along the shore, and throw some of them upon the beach; their dispersing power being aided by the ice, which often adheres to pebbles during the winter months, and gives buoyancy to them.

Among other proofs that the parallel roads have really been formed along the margin of a sheet of water, it may be mentioned, that wherever an isolated hill rises in the middle of the glen above the level of any particular shelf, a corresponding shelf is seen at the same level passing round the hill, as would have happened if it had once formed an island in a lake or fiord.

Those writers who first advocated the doctrine that the roads were the ancient beaches of fresh-water lakes, were unable to offer any probable hypothesis respecting the formation and subsequent removal of barriers of sufficient height and solidity to dam up the water. To introduce any violent convulsion for their removal was inconsistent with the uninterrupted horizontality of the roads, and with the undisturbed aspect of those parts of the glens where the shelves come suddenly to an end. Mr. Agassiz has lately, however, thrown out a conjecture that these valleys were once blocked up by enormous glaciers descending from Ben Nevis, giving rise to what are called in Switzerland, and in the Tyrol, glacier-lakes. After a time the icy barrier was broken down, or melted, first, to the level of the second, and afterwards to that of the third road or shelf.

In corroboration of this view, he contends that the alluvium of Glen Roy, as well as of other parts of Scotland, agrees in character with the moraines of glaciers seen in the Alpine valleys of Switzerland. Allusion will be made in the eleventh chapter to the former existence of glaciers in the Grampians: in the mean time it will readily be conceded that this hypothesis is preferable to any previous lacustrine theory, by accounting more easily for the temporary existence and entire disappearance of lofty transverse barriers, although the height required for the imaginary dams of ice may be startling.

Before the idea last alluded to had been entertained, Mr. Darwin examined Glen Roy, and came to the opinion that the shelves were formed when the glens were still arms of the sea, and, consequently, that there never were any barriers. According to him, the land emerged during a slow and uniform upward movement, like that now experienced throughout a large part of Sweden and Finland; but there were certain pauses in the upheaving process, at which times the waters of the sea remained stationary for so many centuries as to allow of the accumulation of an extraordinary quantity of detrital matter, and the excavation, at points immediately above, of many deep notches and bare cliffs in the hard and solid rock.

The phenomena which are most difficult to reconcile with this theory are, first, the abrupt cessation of the roads at certain points in the different glens; secondly, their unequal number in different valleys connecting with each other, there being three, for example, in Glen Roy and only one in Glen Spean; thirdly, the precise horizontality of level maintained by the same shelf over a space many leagues in length, requiring us to assume, that during a rise of 1250 feet no one portion of the land was raised even a few yards above another.

On the other hand, it may be remarked, in reference to the rival hypothesis of glaciers, that it labors in some degree under precisely the same kind of difficulty, unless we could assume that the land had remained motionless since the era of the liquefaction of the ice. But there are many reasons for presuming that the glacial epoch (granting for the present that there were once glaciers in the Grampians) was antecedent to the deposition of those modern strata, of marine origin, which are found at various heights, from 40 to 400 feet above the sea, in the basins of the Clyde, Forth, Tay, Loch Ness, the Moray Firth, the Hebrides, and many other parts of Scotland. It seems improbable that Glen Roy should have escaped entirely the upward movement experienced in so many surrounding regions, a movement implied by the position of these elevated marine deposits, in which the shells are almost all of known recent species. But if the motion has really extended to Glen Roy and the contiguous glens, it must have uplifted them bodily, without in the slightest degree affecting their horizontality; and this being admitted, the principal objection to the theory of marine beaches, founded on the uniformity of upheaval, meets us equally when we embrace the glacier theory.

The student will perceive, from the above sketch of the controversy respecting the formation of these curious shelves, that this problem, like so many others in geology, is as yet only solved in part; and that a large number of facts must be collected and reasoned upon before the question can be finally settled.

CHAPTER VIII.

ON THE CHRONOLOGY OF ROCKS IN GENERAL.

Aqueous, plutonic, volcanic, and metamorphic rocks, considered chronologically — Lehman's division into primitive and secondary — Werner's addition of a transition class — Neptunian theory — Hutton on igneous origin of granite — How the name of primary was still retained for granite — The term "transition," why faulty — The adherence to the old chronological nomenclature retarded the progress of geology — New hypothesis invented to reconcile the igneous origin of granite to the notion of its high antiquity — Explanation of the chronological nomenclature adopted in this work, so far as regards primary, secondary, and tertiary periods.

In the first chapter it was stated that the four great classes of rocks, the aqueous, the volcanic, the plutonic, and the metamorphic, would each be considered not only in reference to their mineral characters, and mode of origin, but also to their relative age. In regard to the aqueous rocks, we have already seen that they are stratified, that some are calcareous, others argillaceous, some made up of sand, others of pebbles; that some contain freshwater, others marine fossils, and so forth; but the student has still to learn which rocks, exhibiting some or all of these characters, have originated at one period of the earth's history, and which at another.

To determine this point in reference to the fossiliferous formations is more easy than in any other class, and it is therefore the most convenient and natural method to begin by establishing a chronology for these fossiliferous strata, and then to endeavour to refer to the same divisions the several groups of plutonic, volcanic, and metamorphic rocks. This system of classification is not only recommended by its greater clearness and facility of application, but is also best fitted to strike the imagination by bringing into one view the past changes of the inorganic world, and the contemporaneous revolutions of the organic creation. For the sedimentary formations of successive periods are most readily distinguished by the different species of fossil animals and plants which they inclose, and of which one race after another has flourished and then disappeared from the earth.

But before entering specially on the subdivisions of the aqueous rocks arranged according to the order of time, it will be desirable to say a few words on the chronology of rocks in general, although in doing so we shall be led to allude to some classes of phenomena which the beginner must not yet expect fully to comprehend.

It was for many years a received opinion, that the formation of entire families of rocks, such as the plutonic and metamorphic, began and ended before any members of the aqueous and volcanic orders were produced; and although this idea has long been modified, and is nearly exploded, it will be necessary to give some account of the ancient doctrine, in order that beginners may understand whence many prevailing opinions, and some part of the nomenclature of geology, still partially in use, was derived.

About the middle of the last century, Lehman, a German miner, proposed to divide rocks into three classes, the first and oldest to be called primitive, comprising the plutonic and metamorphic rocks; the next to be termed secondary, comprehending the aqueous or fossiliferous strata; and the remainder, or third class, the supposed effect of "local floods, and the deluge of Noah," corresponding to our alluvium, ancient and modern. In the primitive class, he said, such as granite and gneiss, there are no organic remains, nor any signs of materials derived from the ruins of preëxisting rocks. Their origin, therefore, may have been purely chemical, antecedent to the creation of living beings, and probably coeval with the birth of the world itself. The secondary formations, on the contrary, which often contain sand, pebbles, and organic remains, must have been mechanical deposits, produced after the planet had become the habitation of animals and plants. This bold generalization, although anticipated in some measure by Steno, a century before, in Italy, formed at the time an important step in the progress of geology, and sketched out correctly some of the leading divisions into which rocks may be separated. About half a century later, Werner, so justly celebrated for his improved method sof discriminating the mineralogical characters of rocks, attempted to improve Lehman's classification, and with this view intercalated a class, called by him " the transition formations," between the primitive and secondary. Between these last he had discovered, in northern Germany, a series of strata, which in their mineral peculiarities were of an intermediate character, partaking in some degree of the crystalline nature of micaceous and clay-slate, and yet exhibiting here and there signs of a mechanical origin and organic remains. For this group, therefore, forming a passage between Lehman's primitive and secondary rocks, the name of transition was proposed. They consisted principally of clay-slate and an argillaceous sandstone, called greywacké, and partly of calcareous beds. It happened in the district which Werner first investigated, that both the primitive and transition strata were highly inclined, while the beds of the newer and fossiliferous rocks were horizontal. To these latter, therefore, he gave the name of *flötz*, or flat; and every deposit more modern than the chalk, or uppermost of the flötz series, was designated " the overflowed land," an expression which may be regarded as equivalent to alluvium. As the followers of Werner soon discovered that the inclined position of the " transition beds," and the horizontality of the flötz, or newer fossiliferous strata, were mere local accidents, they soon abandoned the term flötz; and the four divisions of the Wernerian school were then named primitive, transition, secondary, and alluvium.

As to the trappean rocks, although their igneous origin had been already demonstrated by Arduino, Fortis, Faujas, and others, and especially by Desmarest, they were all regarded by Werner as aqueous, and as mere subordinate members of the secondary formations.*

This theory of Werner's was called the " Neptunian," and for many years enjoyed much popularity. It assumed that the globe had been at first invested by an universal chaotic ocean, holding the materials of all rocks in solution. From the waters of this ocean, granite, gneiss, and other crystalline formations, were first precipitated; and afterwards, when the waters were purged of these ingredients, and more nearly resembled those of our actual seas, the transition strata were deposited. These were of a mixed character, not purely chemical, because the waves and currents had already begun to wear down solid land, and to give rise to pebbles, sand, and mud; nor entirely without fossils, because a few of the first marine animals had begun to exist. After this period, the secondary formations were accumulated in waters resembling those of the present ocean, except at certain intervals, when, from causes wholly unexplained, a partial recurrence of the "chaotic fluid" took place, during which various trap rocks, some highly crystalline, were formed. This arbitrary hypothesis rejected all intervention of igneous agency, volcanos being regarded as partial and superficial accidents, of trifling account among the great causes which have modified the external structure of the globe.

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* See Principles, vol. i. chap. iv.

Meanwhile Hutton, a contemporary of Werner, began to teach, in Scotland, that granite as well as trap was of an igneous origin, and had at various periods intruded itself in a fluid state into different parts of the earth's crust. He recognised and faithfully described many of the phenomena of granite veins, and the alterations produced by them on the invaded strata, which will be treated of in a future chapter. He, moreover, advanced the opinion, that the crystalline strata called primitive had not been precipitated from a primæval ocean, but were sedimentary strata altered by heat. In his writings, therefore, and in those of his illustrator, Playfair, we find the germ of that metamorphic theory which has been already hinted at in the first chapter, and which will be more fully expounded in the sequel.*

At length, after much controversy, the doctrine of the igneous origin of trap and granite made their way into general favor; but although it was, in consequence, admitted that both granite and trap had been produced at many successive periods, the term primitive or primary still continued to be applied to the crystalline formations in general, whether stratified, like gneiss, or unstratified, like granite. The pupil was told that granite was a primary rock, but that some granites were newer than certain secondary formations; and in conformity with the spirit of the ancient language, to which the teacher was still determined to adhere, a desire was naturally engendered of extenuating the importance of those more modern granites which new observations were continually bringing to light.

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* See chapters on Metamorphic Rock, Vol. II.

A no less decided inclination was shown to persist in the use of the term "transition," after it had been proved to be almost as faulty in its original application as that of flötz. The name of transition, as already stated, was first given by Werner, to designate a mineral character, intermediate between the metamorphic state and that of an ordinary fossiliferous rock. But the term acquired also from the first a chronological import, because it had been appropriated to sedimentary formations, which, in the Hartz and other parts of Germany, were more ancient than the oldest of the secondary series, and were characterized by peculiar fossil zoophytes and shells. When, therefore, geologists found in other districts stratified rocks occupying the same position, and inclosing similar fossils, they gave to them also the name of *transition*, according to rules which will be explained in the next chapter; yet, in many cases, such rocks were found not to exhibit the same mineral texture which Werner had called transition. On the contrary, many of them were not more crystalline than different members of the secondary class; while, on the other hand, these last were sometimes found to assume a semi-crystalline and almost metamorphic aspect, and thus, on lithological grounds, to deserve equally the name of transition. So remarkably was this the case in the Swiss Alps, that certain rocks, which had for years been regarded by some of the most skilful disciples of Werner to be transition, were at last acknowledged, when their relative position and fossils were better understood, to belong to the newest of the secondary groups! If under such circumstances the name of transition was retained, it is clear that it ought to have been applied without reference to the age of strata, and simply as expressive of a mineral peculiarity. The continued appropriation of the term to formations of a given date, induced geologists to go on believing that the ancient strata so designated bore a less resemblance to the secondary than is really the case, and to imagine that these last never pass, as they frequently do, into metamorphic rocks.

The poet Waller, when lamenting over the antiquated style of Chaucer, complains that —

" We write in sand, our language grows,
And, like the tide, our work o'erflows;"

But the reverse is true in geology; for here it is our work which continually outgrows the language. The tide of observation advances with such speed, that improvements in theory outrun the changes of nomenclature; and the attempt to inculcate new truths by words invented to express a different or opposite opinion, tends constantly, by the force of association, to perpetuate error; so that dogmas renounced by the reason still retain a strong hold upon the imagination.

In order to reconcile the old chronological views with the new doctrine of the igneous origin of granite, the following hypothesis was substituted for that of the Neptunists. Instead of beginning with an aqueous menstruum or chaotic fluid, the materials of the present crust of the earth were supposed to have been at first in a state of igneous fusion, until part of the heat having been diffused into surrounding space, the surface of the fluid consolidated, and formed a crust of granite. This covering of crystalline stone, which afterwards grew thicker and thicker, as it cooled, was so hot, at first, that no water could exist upon it; but as the refrigeration proceeded, the aqueous vapor in the atmosphere was condensed, and, falling in rain, gave rise to the first *thermal ocean.* So high was the temperature of this boiling sea, that no aquatic beings could inhabit its waters, and its deposits were not only devoid of fossils, but, like those of some hot springs, were highly crystalline. Hence the origin of the primary or crystalline strata.

Afterwards, when the granite crust had been partially broken up, land and mountains began to rise above the waters, and rains and torrents ground down rock, so that sediment was spread over the bottom of the seas. Yet the heat still remaining in the solid supporting substances was sufficient to increase the chemical action exerted by the water, although not so intense as to prevent the introduction and increase of some living beings. During this state of things some of the residuary mineral ingredients of the primæval ocean were precipitated, and formed deposits, (the transition strata of Werner,) half chemical and half mechanical, and containing a few fossils.

By this new theory, which was in part a revival of the doctrine of Leibnitz, published in 1680, on the igneous origin of the planet, the old ideas respecting the priority of all crystalline rocks to the creation of organic beings, were still preserved; and the notion that all the semi-crystalline and partially fossiliferous rocks belonged to one period, while all the earthly and uncrystalline formations originated at a subsequent epoch, was also perpetuated.

It may or may not be true, as the great Leibnitz imagined, that the whole planet was once in a state of liquefaction by heat; but there are certainly no geological proofs that the granite which constitutes the foundation of so much of the earth's crust was ever at once in a state of universal fusion. On the contrary, all our evidence tends to show that the formation of granite, like the deposition of the stratified rocks, has been successive, and that different portions of granite have been in a melted state at distinct and often distant periods. One mass was solid, and had been fractured, before another body of granitic matter was injected into it, or through it, in the form of veins. In short, the universal fluidity of the crystalline foundations of the earth's crust, can only be understood in the same sense as the universality of the ancient ocean. All the land has been under water, but not all at one time; so all the subterranean unstratified rocks to which man can obtain access have been melted, but not simultaneously.

In the present work the four great classes of rocks, the aqueous, plutonic, volcanic, and metamorphic, will form four parallel, or nearly parallel, columns in one chronological table. They will be considered as four sets of monuments relating to four contemporaneous, or nearly contemporaneous, series of events. I have endeavoured, in the Frontispiece, and in a subsequent chapter on the plutonic rocks, to express the manner in which members of each of the four classes may have originated simultaneously at every geological period. According to this view, the earth's crust may have been continually remodelled, above and below, by aqueous and igneous causes, from times indefinitely remote. In the same manner as aqueous and fossiliferous strata are now formed in certain seas or lakes, while in other places volcanic rocks break out at the surface, and are connected with reservoirs of melted matter at vast depths in the bowels of the earth, — so, at every era of the past, fossiliferous deposits and superficial igneous rocks were in progress contemporaneously with others of subterranean and plutonic origin, and some sedimentary strata were exposed to heat and made to assume a crystalline or metamorphic structure.

It can by no means be taken for granted, that during all these changes the solid crust of the earth has been increasing in thickness. It has been shown, that so far as aqueous action is concerned, the gain by fresh deposits, and the loss by denudation, must at each period have been equal; and in like manner, in the inferior portion of the earth's crust, the acquisition of new crystalline racks, at each successive era, may merely have counterbalanced the loss sustained by the melting of materials previously consolidated. As to the relative antiquity of the crystalline foundations of the earth's crust, when compared to the fossiliferous and volcanic rocks which they support, I have already stated, in the first chapter, that to pronounce an opinion on this matter is as difficult as at once to decide which of the two, whether the foundations or superstructure of an ancient city built on wooden piles may be the oldest. We have seen that to answer this question, we must first be prepared to say whether the work of decay and restoration had gone on most rapidly above or below, whether the average duration of the piles has exceeded that of the stone buildings, or the contrary. So also in regard to the relative age of the superior and inferior portions of the earth's crust; we cannot hazard even a conjecture on this point, until we know whether, upon an average, the power of water above, or that of fire below, is most efficacious in giving new forms to solid matter.

After the observations which have now been made, the reader will perceive that the term primary must either be entirely renounced, or, if retained, must be differently defined, and not made to designate a set of crystalline rocks, some of which may be newer than the secondary formations. In this work I shall follow most nearly the method proposed by Mr. Boué, who has called all fossiliferous rocks older than the secondary by the name of primary, which thus becomes a substitute for the term transition, so far as regards the aqueous strata. To prevent confusion, however, I shall always speak of these as the *primary fossiliferous* formations, because the word primary has hitherto been almost inseparably connected with the idea of a non-fossiliferous rock.

If we can prove any plutonic, volcanic, or metamorphic rocks to be older than the secondary formations, such rocks will also be primary, according to this system. Mr. Boué having with great propriety excluded the metamorphic rocks, *as a class*, from the primary formations, proposed to call them all "crystalline schists," restricting the name of primary to the older fossiliferous or transition strata.

As there are secondary fossiliferous strata, so we shall find that there are plutonic, volcanic, and metamorphic rocks of contemporaneous origin, which I shall also term secondary.

In the next chapter it will be shown that the strata above the chalk have been called tertiary. If, therefore, we discover any volcanic, plutonic, or metamorphic rocks, which have originated since the deposition of the chalk, these also will rank as tertiary formations.

It may perhaps be suggested that some metamorphic strata, and some granites, may be anterior in date to the oldest of the primary fossiliferous rocks. The opinion is certainly not improbable, and will be discussed in future chapters; but I may here observe, that when we arrange the four classes of rocks in four parallel columns in one table of chronology, it is by no means assumed that these columns are all of equal length; one may begin at an earlier period than the rest, and another may come down to a later point of time. In the small part of the globe hitherto examined, it is hardly to be expected that we should have discovered either the oldest or the newest of all the four classes of rocks. Thus, if there be primary, secondary, and tertiary rocks of the fossiliferous classes, and in like manner primary, secondary, and tertiary plutonic formations, we may not be yet acquainted with the most ancient of the primary fossiliferous beds, or with the newest of the plutonic, and so of the rest.

CHAPTER IX.

ON THE DIFFERENT AGES OF THE AQUEOUS ROCKS.

On the three principal tests of relative age—superposition, mineral character, and fossils — Change of mineral character, and fossils in the same continuous formation — Proofs that distinct species of animals and plants have lived at successive periods — Distinct provinces of indigenous species — Great extent of single provinces — Similar laws prevailed at successive geological periods — Relative importance of mineral and palæontological characters — Test of age by included fragments — Frequent absence of strata of intervening periods — Principal groups of strata in western Europe — Post-Pliocene formations defined — Fossil shells — Recent and Post-Pliocene strata of Naples, Sweden, Norway, South America, the West Indies, and Great Britain.

In the last chapter I spoke generally of the chronological relations of the four great classes of rocks, and I shall now treat of the aqueous rocks in particular, or of the successive periods at which the different fossiliferous formations have been deposited.

Now there are three principal tests by which we determine the age of a given set of strata; first, superposition; secondly, mineral character; and, thirdly, organic remains. Some aid can occasionally be derived from a fourth kind of proof, namely, the fact of one deposit including in it fragments of a preëxisting rock, by which the relative ages of the two may, even in the absence of all other evidence, be determined.

Superposition. — The first and principal test of the age of one aqueous deposit, as compared to another, is relative position. It has been already stated, that where the strata are horizontal, the bed which lies uppermost is the newest of the whole, and that which lies at the bottom the most ancient. So, of a series of sedimentary formations, they are like volumes of history, in which each writer has recorded the annals of his own times, and then laid down the book, with the last written page uppermost, upon the volume in which the events of the era immediately preceding were commemorated. In this manner a lofty pile of chronicles is at length accumulated; and they are so arranged as to indicate, by their position alone, the order in which the events recorded in them have occurred.

In regard to the crust of the earth, however, there are some regions where, as the student has already been informed, the beds have been disturbed, and sometimes reversed. (See pp. 124, 125.) But the experienced geologist will not be deceived by these exceptional cases. When he finds that the strata are fractured, curved, inclined, or vertical, he knows that the original order of superposition must be doubtful, and he will endeavour to find sections in some neighbouring district where the strata are horizontal, or only slightly inclined. Here, it is impossible that they can have been extensively thrown over and turned upside down, for such a derangement cannot have taken place throughout a wide area without leaving manifest signs of displacement and dislocation.

Mineral character. — The same rocks may often be observed to retain for miles, or even hundreds of miles, the same mineral peculiarities, if we follow the planes of stratification, or trace the beds, if they be undisturbed, in a horizontal direction. But if we pursue them vertically, or in any direction transverse to the planes of stratification, this uniformity ceases almost immediately. In that case we can scarcely ever penetrate a stratified mass for a few hundred yards without beholding a succession of extremely dissimilar, calcareous, argillaceous, and siliceous rocks. These phenomena lead to the conclusion, that rivers and currents have dispersed the same sediment over wide areas at one period, but at successive periods have been charged, in the same region, with very different kinds of matter. The first observers were so astonished at the vast spaces over which they were able to follow the same homogeneous rocks in a horizontal direction, that they came hastily to the opinion, that the whole globe had been environed by a succession of distinct aqueous formations, disposed round the nucleus of the planet, like the concentric coats of an onion. But although, in fact, some formations may be continuous over districts as large as half of Europe, or even more, yet most of them either terminate wholly within narrower limits, or soon change their lithological character. Sometimes they thin out gradually, as if the supply of sediment had failed in that direction, or they come abruptly to an end, as if we had arrived at the borders of the ancient sea or lake which served as their receptacle. It no less frequently happens that they vary in mineral aspect and composition, as we pursue them horizontally. For example, we trace a limestone for a hundred miles, until it becomes more arenaceous, and finally passes into sand, or sandstone. We may then follow this sandstone, already proved by its continuity to be of the same age, throughout another district a hundred miles or more in length.

Organic remains. — This character must be used as a criterion of the age of a formation, or of the contemporaneous origin of two deposits in distant places, under very much the same restrictions as the test of mineral composition.

First, the same fossils may be traced over wide regions, if we examine strata in the direction of their planes, although by no means for indefinite distances.

Secondly, while the same fossils prevail in a particular set of strata for hundreds of miles in a horizontal direction, we seldom meet with the same remains for many fathoms, and very rarely for several hundred yards, in a vertical line, or a line transverse to the strata. This fact has now been verified in almost all parts of the globe, and has led to a conviction, that at successive periods of the past, the same area of land and water has been inhabited by species of animals and plants as distinct as those which now people the antipodes, or which now coexist in the arctic, temperate, and tropical zones. It appears, that from the remotest periods there has been ever a coming in of new organic forms, and an extinction of those which preëxisted on the earth; some species having endured for a longer, others for a shorter time; while none have ever reappeared after once dying out. The law which has governed the creation and extinction of species seems to be expressed in the verse of the poet, —

> "Natura il fece, e poi ruppe la stampa." ARIOSTO.
>
> Nature made it, and then broke the die.

And this circumstance it is which confers on fossils their highest value as chronological tests, giving to each of them, in the eyes of the geologist, that authority which belongs to contemporary medals in history.

The same cannot be said of each peculiar variety of rock; for some of these, as red marl and red sandstone, for example, may occur at once at the top, bottom, and middle of the entire sedimentary series; exhibiting in each position so perfect an identity of mineral aspect as to be undistinguishable. Such exact repetitions, however, of the same mixtures of sediment have not often occurred, at distant periods, in precisely the same parts of the globe; and even where this has happened, we may usually avoid confounding together the monuments of remote eras, by the aid of fossils and relative position.

It was remarked that the same species of fossils cannot be traced horizontally, or in the direction of the planes of stratification for indefinite distances. This might have been expected from analogy; for when we inquire into the present distribution of organic beings, we find that the habitable surface of the sea and land may be divided into a considerable number of distinct provinces, each peopled by a peculiar assemblage of animals and plants. In the Principles of Geology, I endeavoured to point out the probable origin of these separate divisions; and it was shown that climate is only one of many causes on which they depend, and that difference of longitude as well as latitude is generally accompanied by a dissimilarity of indigenous species.

As different seas, therefore, and lakes are inhabited at the same period, by different aquatic animals and plants, and as the lands adjoining these may be peopled by distinct terrestrial species, it follows that distinct fossils will be imbedded in contemporaneous deposits. If it were otherwise — if the same species abounded in every climate, or in every part of the globe where, so far as we can discover, a corresponding temperature and other conditions favorable to their existence are found — the identification of mineral masses of the same age, by means of their included organic contents, would be a matter of much greater facility.

But the extent of the same zoological provinces, especially those of marine animals, is very great; and our geological researches have proved that the same laws prevailed at remote periods; for the fossils are often identical throughout wide spaces, and in a great number of detached deposits, in which the mineral nature of the rocks is variable.

The doctrine here laid down will be more readily understood, if we reflect on what is now going on in the Mediterranean. That entire sea may be considered as one zoological province; for, although certain species of testacea and zoophytes may be very local, and each region has probably some species peculiar to it, still a considerable number are common to the whole Mediterranean. If, therefore, at some future period, the bed of this inland sea should be converted into land, the geologist might be enabled, by reference to organic remains, to prove the contemporaneous origin of various mineral masses scattered over a space equal in area to the half of Europe.

The deposits alluded to are those which are well known to be now in progress in the deltas of the Po, Rhone, Nile, and other rivers, the sediment of which differs as greatly as does the composition of the mountains which they drain. There are also other quarters of the Mediterranean, as off the coast of Campania, or near the base of Etna, in Sicily, or in the Grecian Archipelago, where other kinds of rocks are now forming. Occasional showers of volcanic ashes fall into the sea, and streams of lava overflow its bottom; and in the intervals between volcanic eruptions, beds of sand and clay are frequently derived from the waste of cliffs, or the turbid waters of rivers. Limestones, moreover, such as the Italian travertins, are here and there precipitated from the waters of mineral springs, some of which rise up from the bottom of the sea. In all these detached formations, so diversified in their lithological characters, the remains of the same shells, corals, crustacea, and fish are becoming inclosed; or, at least, a sufficient number must be common to the different localities to enable the zoologist to refer them all to one contemporaneous assemblage of species.

There are, however, certain combinations of geographical circumstances which cause distinct provinces of animals and plants to be separated from each other by very narrow limits; and hence it must happen, that strata will be sometimes formed in contiguous regions, differing widely both in mineral contents and organic remains. Thus, for example, the testacea, zoophytes, and fish of the Red Sea are, as a group, extremely distinct from those inhabiting the adjoining parts of the Mediterranean, although the two seas are separated only by the narrow isthmus of Suez. Calcareous formations have accumulated on a great scale in the Red Sea in modern times, and fossil shells of existing species are well preserved therein; and we know that at the mouth of the Nile large deposits of mud are amassed, including the remains of Mediterranean species. It follows, therefore, that if at some future period the bed of the Red Sea should be laid dry, the geologist might experience great difficulties in endeavouring to ascertain the relative age of these formations, which, although dissimilar both in organic and mineral characters were of synchronous origin.

But we must not forget that the northwestern shores of the Arabian Gulf, the plains of Egypt, and the isthmus of Suez, are all parts of one province of *terrestrial* species. Small streams, therefore, occasional land-floods, and those winds which drift clouds of sand along the deserts, might carry down into the Red Sea the same shells of fluviatile and land testacea which the Nile is sweeping into its delta, together with some remains of terrestrial plants, whereby the groups of strata, before alluded to, might, notwithstanding the discrepancy of their mineral composition, and *marine* organic fossils, be shown to have belonged to the same epoch.

But while rivers may thus carry down the same fluviatile and terrestrial spoils into two or more seas inhabited by different marine species, it will much more frequently happen, that the coexistence of terrestrial species of distinct zoological and botanical provinces will be proved by the identity of the marine beings which inhabited the intervening space. Thus, for example, the land quadrupeds and shells of the south of Europe, north of Africa, and northwest of Asia, are different, yet their remains are all washed down by rivers flowing from these three countries into the Mediterranean.

In some parts of the globe, at the present period, the line of demarcation between distinct provinces of animals and plants is not very strongly marked, especially where the change is determined by temperature, as in seas extending from the temperate to the tropical zone, or from the temperate to the arctic regions. Here a gradual passage takes place from one set of species to another. In like manner the geologist, in studying particular formations of remote periods, has sometimes been able to trace the gradation from one ancient province to another, by observing carefully the fossils of all the intermediate places. His success in thus acquiring a knowledge of the zoological or botanical geography of very distant eras has been mainly owing to this circumstance, that the mineral character has no tendency to be affected by climate. A large river may convey yellow or red mud into some part of the ocean, where it may be dispersed by a current over an area several hundred leagues in length, so as to pass from the tropics into the temperate zone. If the bottom of the sea be afterwards upraised, the organic remains imbedded in such yellow or red strata may indicate the different animals or plants which once inhabited at the same time the temperate and equatorial regions.

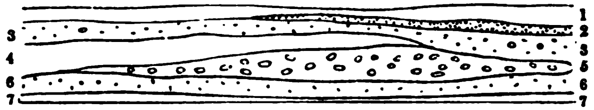
It may be true, as a general rule, that groups of the same species of animals and plants may extend over wider areas than deposits of homogeneous composition; and if so, palæontological characters will be of more importance in geological classification than mineral composition; but it is idle to discuss the relative value of these tests, and it fortunately happens, that where the one criterion fails, we can often avail ourselves of the other.

Test by included fragments of older rocks. — It was stated, that independent proof may sometimes be obtained of the relative date of two formations, by fragments of an older rock being included in a newer one. This evidence may sometimes be of great use, where a geologist is at a loss to determine the relative age of two formations, from want of clear sections exhibiting their true order of position, or because the strata of each group are vertical. In such cases we sometimes discover that the more modern rock has been in part derived from the degradation of the older. Thus, for example, we may find in one part of a country chalk with flints; and, in another, a distinct formation, consisting of alternations of clay, sand, and pebbles. If some of these pebbles consist of flints, with fossil shells of the same species as those in the chalk, we may confidently infer that the chalk is the oldest of the two formations.

Chronological groups. — The number of groups into which the fossiliferous strata may be separated are more or less numerous, according to the views of classification which different geologists entertain; but when we have adopted a certain system of arrangement, we immediately find that a few only of the entire series of groups occur one upon the other in any single section or district.

The thinning out of individual strata was before described (p. 34.). But let the annexed diagram

Fig. 100.



represent seven fossiliferous groups, instead of as many strata. It will then be seen that in the middle all the superimposed formations are present; but in consequence of some of them thinning out, No. 2. and No. 5. are absent at one extremity of the section, and No. 4. at the other.

If the reader consults the Frontispiece, he will see, that as the yellow-colored strata A rest unconformably upon the older groups, *c*, *e*, *f*, *g*, we should meet with a very different succession in a vertical section exposed at different places; in one spot the beds A, lying immediately on *c*, in another on *g*, and so forth. Now here the difference has been partly occasioned by denudation; the formations *a*, *b*, for instance, once extended much further to the left, and but for denudation would have been everywhere interposed between

A and the rocks *e*, *f*, *g*. In many instances the entire absence of one or more formations of intervening periods between two groups, such as A and *c* (see Frontispiece), arises, not from the destruction of what once existed, by denudation, but because no strata of an intermediate age were ever deposited on *c*. They were not formed at that place, either because the region was dry land during the interval, or because it was part of a sea or lake to which no sediment was carried.

In order, therefore, to establish a chronological succession of fossiliferous groups, a geologist must begin with a single section, in which several sets of strata lie one upon the other. He must then trace these formations, by attention to their mineral character and fossils, continuously, as far as possible, from the starting point. As often as he meets with new groups, he must ascertain by superposition their age relatively to those first examined, and thus learn how to intercalate them in a tabular arrangement of the whole.

By this means the German, French, and English geologists have determined the succession of strata throughout a great part of Europe, and have adopted pretty generally the following groups, almost all of which have their representatives in the British Islands.

Groups of Fossiliferous Strata observed in Western Europe, arranged in what is termed a descending Series, or beginning with the newest.

1. Post-Pliocene, including those of the Recent, or human period.	
2. Newer Pliocene.	Tertiary or Supracretaceous.*
3. Older Pliocene.	
4. Miocene.	
5. Eocene.	
6. Chalk.	Secondary.
7. Greensand.	
8. Wealden.	
9. Upper Oolite.	
10. Middle Oolite.	
11. Lower Oolite.	
12. Lias.	
13. Upper New Red Sandstone and Muschelkalk.	
14. Lower New Red and Magnesian limestone.	
15. Coal.	
16. Old Red Sandstone and Devonian.	
17. Upper Silurian.	Primary fossiliferous (or transition of some authors.)
18. Lower Silurian.	
19. Cambrian and older fossiliferous strata.	

A glance at the above table will show that the three principal sections, called primary fossiliferous, secondary, and tertiary, are by no means of equivalent importance, if the eighteen subordinate groups comprise monuments relating to equal portions of past time, or of the earth's history. But this we cannot assert; but merely know that they each relate to successive periods, during which certain animals and plants, for the most part peculiar to that era, flourished, and during which different kinds of sediment were deposited in the space now occupied by Europe.

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* For tertiary, M. De la Beche has used the term "supracretaceous," a name implying that the strata so called are superior in position to the chalk.

If we were disposed, on palæontological grounds, to divide the entire fossiliferous series into a few groups, less numerous than those in the above table, and more nearly coördinate in value than the sections called primary, secondary, and tertiary, we might, perhaps, adopt the six following groups or periods.*

Fossiliferous Strata of Western Europe divided into Six Groups.

1. Post-Pliocene and Tertiary	from the Post-Pliocene to the Eocene inclusive.
2. Cretaceous	from the Chalk to the Wealden inclusive.
3. Oolitic	from the Portland Oolite to the Lias inclusive.
4. Upper New Red	including the Keuper, Muschelkalk, and Bunter Sandstein of the Germans.
5. Lower New Red and Carboniferous	including Magnesian Limestone (Zechstein), Coal, and Old Red sandstone.
6. Primary fossiliferous	from the Upper Silurian to the oldest fossiliferous rocks inclusive.

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* Pelæontology is the science which treats of fossil re-

At the same time I may observe, that in the present state of the science, when we have not yet compared the evidence derivable from all classes of fossils, not even those most generally distributed, such as shells, corals, and fish, such generalizations are premature, and can only be regarded as conjectural schemes for the founding of large natural groups.

In the first of the foregoing tables (p. 210.) I have adopted the term Post-Pliocene for those strata, which are sometimes called modern, and which are characterized by having all the imbedded fossil shells indentical with species now living, whereas even the Newer Pliocene or newest of the tertiary deposits contain always some small proportion of shells of extinct species.*

These modern formations, thus defined, comprehend not only those strata which can be shown to have originated since the earth was inhabited by man, but also deposits of far greater extent and thickness, in which no signs of man or his works can be detected. In some of these, of a date long anterior to the times of history and tradition, the bones of extinct quadrupeds have been met with of species which probably never

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mains, both animal and vegetable. *Etym.* παλαιὸς, *palaios*, ancient, ὄντα, *onta*, beings, λόγος, *logos*, a discourse.

* See explanation of the term Pliocene, chap. xii.

coexisted with the human race, as, for example, the mammoth, and yet the shells are the same as those now living.

Before enlarging further on these topics, it may be well to explain why the testacea are selected as the most useful and convenient class of fossil remains for the purposes of general classification. In the first place, they are more universally distributed through strata of every age than any other organic bodies. Those families of fossils which are of rare and casual occurrence are absolutely of no avail in establishing a chronological arrangement. If we have plants alone in one group of strata and the bones of mammalia in another, we can draw no conclusion respecting the affinity or discordance of the organic beings of the two epochs compared; and the same may be said if we have plants and vertebrated animals in one series and only shells in another. Although corals are more abundant, in a fossil state, than plants, reptiles, or fish, they are still rare when contrasted with shells, especially in the European tertiary formations. The utility of the testacea is, moreover, enhanced by the circumstance that some forms are proper to the sea, others to the land, and others to freshwater. Rivers scarcely ever fail to carry down into their deltas some land shells, together with species which are at once fluviatile and lacustrine. By this means we learn what terrestrial, freshwater, and marine species coexisted at particular eras of the past; and having thus identified strata formed in seas, with others which originated contemporaneously in inland lakes, we are then enabled to advance a step further, and show that certain quadrupeds or aquatic plants, found fossil in lacustrine formations, inhabited the globe at the same period when certain fish, reptiles, and zoophytes lived in the ocean.

Among other characters of the molluscous animals, which render them extremely valuable in settling chronological questions in geology, may be mentioned, first, the wide geographical range of many species; and, secondly, what is probably a consequence of the former, the great duration of species in this class, for they appear to have surpassed in longevity the greater number of the mammalia and fish. Had each species inhabited a very limited space, it could never, when imbedded in strata, have enabled the geologist to identify deposits at distant points; or had they each lasted but for a brief period, they could have thrown no light on the connexion of rocks placed far from each other in the chronological, or, as it is often termed, vertical series.

That portion of the post-pliocene group which belongs to the human epoch, and which is sometimes called *Recent*, forms a very insignificant feature in the geological structure of the earth's crust. I have shown, however, in another work, where the recent changes of the earth illustrative of geology are described at length, that the deposits accumulated at the bottom of lakes and seas within the last 4000 or 5000 years can neither be insignificant in volume or extent. They lie hidden, for the most part, from our sight; but we have opportunities of examining them at certain points where newly-gained land in the deltas of rivers has been cut through during floods, or where coral reefs are growing rapidly, or where the bed of a sea or lake has been heaved up by subterranean movements and laid dry. Their age may be recognised either by our finding in them the bones of man in a fossil state, that is to say, imbedded in them by natural causes, or by their containing articles fabricated by the hands of man.

Thus at Puzzuoli, near Naples, marine strata are seen containing fragments of sculpture, pottery, and the remains of buildings, together with innumerable shells retaining in part their color, and of the same species as those now inhabiting the Bay of Baiæ. The uppermost of these beds is about twenty feet above the level of the sea. Their emergence can be proved to have taken place since the beginning of the sixteenth century.* Now here, as in almost every instance where any alterations of level have been going on in historical periods, it is found that rocks containing shells, all, or nearly all of which still inhabit the neighbouring sea, may be traced for some distance into the interior, and often to a considerable elevation above the level of the sea. Thus, in the country round Naples, the post-pliocene strata, consisting of clay and horizontal beds of volcanic tuff, rise at certain points to the height of 1500 feet. Although the marine shells are exclusively of living species, they are not accompanied like those on the coast at Puzzuoli by any traces of man or his works. Had any such been discovered, it would have afforded to the antiquary and geologist matter of great surprise, since it would have shown that man was an inhabitant of that part of the globe, while the materials composing the present hills and plains of Campania were still in the progress of deposition at the bottom of the sea; whereas we know that for nearly 3000 years, or from the times of the earliest Greek colonists, no material revolution in the physical geography of that part of Italy has occurred.

In Ischia, a small island near Naples, composed in like manner of marine and volcanic formations,

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* See Principles, Index, "Serapis."

Dr. Philippi collected in the stratified tuff and clay ninety-two species of shells, all of which, except three, are already known to exist in the Mediterranean, and the others may yet perhaps be discovered. In the centre of Ischia, the lofty hill called Epomeo, or San Nicola, is composed of greenish indurated tuff, of a prodigious thickness, interstratified in some parts with marl, and here and there with great beds of solid lava. Visconti ascertained by trigonometrical measurement, that this mountain was 2605 feet above the level of the sea. Not far from its summit, at the height of about 2000 feet, as also near Moropano, a village only 100 feet lower, on the southern declivity of the mountain, I collected, in 1828, many shells of species now inhabiting the neighbouring gulf. It is clear, therefore, that the great mass of Epomeo was not only raised to its present height, but was also *formed* beneath the waters, within the Post-Pliocene period.

In Sweden, analogous phenomena have been observed. Near Stockholm, for example, when the canal of Södertelje was dug, horizontal beds of sand, loam, and marl were passed through, in some of which the same peculiar assemblage of testacea which now live in the brackish waters of the Baltic were found. Mingled with these, at different depths, were detected various works of art implying a rude state of civilization, and some vessels built before the introduction of iron. These vessels and implements must have sunk to the bottom of an arm of the sea, afterwards filled up with sand and loam inclosing marine shells, and the whole must then have been upraised; so that the upper beds became sixty feet higher than the surface of the Baltic. In the neighbourhood of these recent strata, both to the northwest and south of Stockholm, other deposits similar in mineral composition occur, which ascend to greater heights, in which precisely the same assemblage of fossil shells is met with, but without any intermixture of human bones or fabricated articles.

On the opposite or western coast of Sweden, at Uddevalla, Post-Pliocene strata, containing recent shells, such as now live in the northern ocean, ascend to the height of 200 feet; and beds of clay and sand of the same age attain elevations of 300 and even 600 feet in Norway, where they have been usually described as raised beaches. They are, however, thick deposits of submarine origin, spreading far and wide, and filling valleys in the granite and gneiss, just as the tertiary formations, in different parts of Europe, cover or fill depressions in the older rocks. It has been ascertained that, in various parts of Finland and Sweden, land has been rising gradually at the rate of a few feet, and sometimes only a few inches, in a century, above its former level; and similar movements must evidently have been experienced in Norway, since the ocean was peopled with the species of testacea now inhabiting its waters.

Examples might be cited in all parts of the world of the same phenomena. Thus, Recent strata have been traced along the coasts of Peru and Chili, inclosing shells in abundance, all agreeing specifically with those now swarming in the Pacific. In one bed of this kind, in the island of San Lorenzo, near Lima, Mr. Darwin found, at the altitude of eighty-five feet above the sea, pieces of cotton-thread, plaited rush, and the head of a stalk of Indian corn, the whole of which had evidently been imbedded with the shells. At the same height on the neighbouring mainland, he found other signs corroborating the opinion that the ancient bed of the sea had there also been uplifted eighty-five feet, since the region was first peopled by the Peruvian race.* But similar shelly masses are also met with at much higher elevations, at innumerable points between the Chilian and Peruvian Andes, and the sea-coast, in which no human remains were ever, or in all probability ever will be, discovered.

In the West Indies, also, in the island of Guadaloupe, a solid limestone occurs, at the level of the sea-beach, enveloping human skeletons. The stone is extremely hard, and chiefly composed of comminuted shell and coral, with here and there some entire corals and shells, of species now living in the adjacent ocean. With them are included arrow-heads, fragments of pottery, and other articles of human workmanship. A limestone with similar contents has been formed, and is still forming, in St. Domingo. But there are also more ancient rocks in the West Indian Archipelago, as in Cuba, near the Havana, and in other islands, in which are shells identical with those now living in corresponding latitudes; some well preserved, others in the state of casts, all referable to the Post-Pliocene period.

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* Journal, p. 451.

In England, buried ships have been found in the former and now deserted channels of the Rother in Sussex, of the Mersey in Kent, and the Thames near London. Canoes and stone-hatchets have been dug up, in almost all parts of the kingdom, from peat and shell-marl; but there is no evidence, as in Sweden, Italy, Peru, Chili, and other parts of the world, of the bed of the sea, and the adjoining coast, having been uplifted bodily in recent times. In Ireland, however, the greater part of a human skeleton has been lately found at Waterford Haven, in an undisturbed marine stratum, containing the common mussel, cockle, and other shells of recent species, some of which were found in the cavity of the skull. The bed consisted of sand and clay, and was five feet below the surface of the soil, and five feet above the level of high-tide. Other parts of the same formation extend eight miles inland, and reach a height of forty feet above the sea.*

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* T. Austin, Proceedings Geol. Soc. No. 74.

CHAPTER X.

BOULDER FORMATION, ITS AGE, AND ORIGIN.

Boulder formation of Scandinavia, Russia, and northern Germany described — Till — Erratics diminishing in size when traced southwards — They rest on Post-Pliocene strata in Russia and Sweden — Drift of eastern Norfolk — Associated freshwater deposit — Bent and folded strata lying on horizontal and undisturbed beds — Lateral pressure of stranded icebergs — Drifting of stones by ice in northern and southern hemispheres — Cause of non-stratification of Till — Buried forest in Norfolk — Boulder formation of Canada, and arctic character of accompanying shells.

MENTION was made in the seventh chapter of an ancient alluvium in the north of Europe, called the "boulder formation," the peculiar characters and probable age of which must now be considered. I shall first describe briefly that portion of it which extends from Finland and the Scandinavian mountains to the north of Russia, and the low countries bordering the Baltic, and which has been traced southwards as far as the eastern coast of England. This formation consists of mud, sand, and clay, sometimes stratified, but often wholly devoid of stratification, for a depth of more than a hundred feet. To this unstratified form of the deposit, the name of *till* has been applied in Scotland. It generally contains numerous fragments of rocks, some angular and others rounded, which have been derived from formations of all ages, both fossiliferous, volcanic, and hypogene, and which have often been brought from great distances. Some of the travelled blocks are of enormous size, several feet or yards in diameter; their average dimensions increasing as we advance northwards. The till is almost everywhere devoid of organic remains, unless where these have been washed into it from older formations; so that it is chiefly from relative position that we must hope to derive a knowledge of its age.

Although a large proportion of the boulder deposit is made up of fragments brought from a distance, and which have sometimes travelled many hundred miles, the bulk of the mass in each locality consists of the ruins of subjacent or neighbouring rocks; so that it is red in a region of red sandstone, white in a chalk country, and gray or black in a district of coal and coal-shale.

Northern origin of erratics. — That the erratics of northern Europe have been carried southward, cannot be doubted; those of granite, for example, scattered over large districts of Russia and Poland, agree precisely in character with rocks of the mountains of Lapland and Finland; while the masses of gneiss, syenite, porphyry, and trap, strewed over the low sandy countries of Pomerania, Holstein, and Denmark, are identical in mineral characters with the mountains of Norway and Sweden.

It is found to be a general rule in Russia, that the smaller blocks are carred to greater distances from their point of departure than the larger; the distance being sometimes 800 and even 1000 miles from the nearest rocks, from which they were broken off; the direction having been from N. W. to S. E., or from the Scandinavian mountains over the seas and low lands to the southeast.

When we have once ascertained that the main direction of the continuous stream of blocks was from Scandinavia towards more southern latitudes, and when we have traced it from Denmark across the Elbe, and through Westphalia, to the borders of Holland, we are the less surprised to find it reappear on our eastern coast, between the Tweed and the Thames, regions not half so remote from parts of Norway as are many Russian erratics from the sources whence they came. That its accumulation throughout this area took place wholly, or in great part, during the Post-Pliocene period is proved by its superposition at several points to strata containing recent shells. Thus, for example, in European Russia, M. M. Murchison and De Verneuil found, in 1840, that the flat country between St. Petersburgh and Archangel, for a distance of 600 miles, consisted of horizontal strata, full of shells similar to those now inhabiting the arctic sea, on which rested the boulder formation, containing large erratics.

In Sweden, in the immediate neighbourhood of Upsala, I observed, in 1834, a ridge of stratified sand and gravel, in the midst of which is a layer of marl, evidently formed originally at the bottom of the Baltic, by the slow growth of the mussel, cockle, and other marine shells intermixed with some of freshwater species. The marine shells are all of dwarfish size, like those now inhabiting the brackish waters of the Baltic; and the marl, in which myriads of them are imbedded, is now raised more than 100 feet above the level of the Gulf of Bothnia. Upon the top of this ridge repose several huge erratics, consisting of gneiss for the most part unrounded, from nine to sixteen feet in diameter, and which must have been brought into their present position since the time when the neighbouring gulf was already characterized by its peculiar fauna.* Here, therefore, we have proof that the transport of erratics continued to take place, not merely when the sea was inhabited by the existing testacea, but when the north of Europe had already assumed that remarkable feature of its physical geography, which causes the Gulf of Bothnia to have only one fourth of the saltness belonging to the ocean. In Denmark, also, recent shells have been found in stratified beds, closely associated with the boulder clay.

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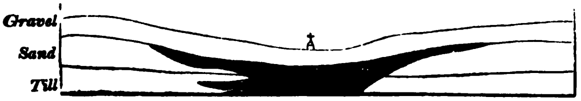
* See paper by the author, Phil. Trans. 1835, p. 15.

Norfolk drift. — The same association recurs in England, where the boulder deposit may be studied with the greatest advantage in the cliffs of the Norfolk coast, between Happisburgh and Cromer. Vertical sections, having an ordinary height of from 50 to 70 feet, are there exposed to view for a distance of about 20 miles. The name of diluvium was formerly given to it by those who supposed it to have been produced by the violent action of a sudden and transient deluge, but the term drift has been substituted by those who reject this hypothesis. Here, as elsewhere, it consists for the most part of clay, loam, and sand, in part stratified, in part devoid of stratification. Pebbles, together with some large boulders of granite, porphyry, greenstone, lias, chalk, and other transported rocks, are interspersed, especially through the till. White chalk rubble, unmixed with foreign matter, and even huge fragments of solid chalk, also occur in many localities. No fossils have been detected in this drift, which can positively be referred to the era of its accumulation; but at some points it overlies a freshwater formation containing recent shells, and at others it is blended with the same in such a manner as to force us to conclude that both were contemporaneously deposited.

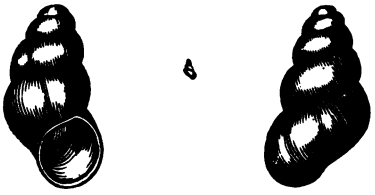
Fig. 101.



Intercalation of the freshwater beds and boulder clay at Mundesley.

This interstratification is expressed in the annexed figure, the dark mass indicating the position of the freshwater beds, which contain much vegetable matter, and are divided into thin layers. The imbedded shells belong to the genera *Planorbis*, *Limnea*, *Paludina*, *Unio*, *Cyclas*, and others, all of British species, except a minute *Paludina* now inhabiting France. (See Fig. 102.)

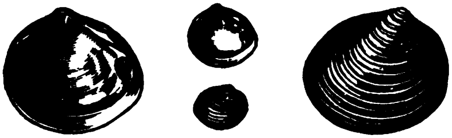
Fig. 102.



Paludina marginata, Michaud. (*P. minuta*, Strickland.)
The middle figure is of the natural size.

The *Cyclas* (Fig. 103.) is merely a remarkable

Fig. 103.

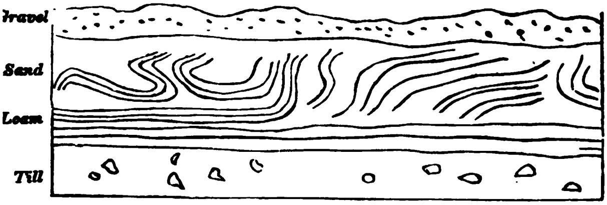


Cyclas (Pisidium) amnica, var. ?
The two middle figures are of the natural size.

variety of the common English species. The scales and teeth of fish of the genera Pike, Perch, Roach, and others, accompany these shells; but the species are not considered by M. Agassiz to be identical with known British or European kinds. If all the shells, therefore, of these freshwater beds, when more thoroughly investigated, should prove to be of recent species, the associated Norfolk drift must be referred to part of the Post-Pliocene period.

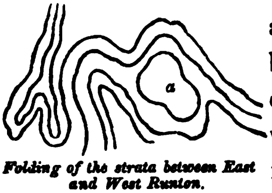
The series of formations in the cliffs of eastern Norfolk, now under consideration, beginning with the lowest, is as follows: — First, chalk; secondly, patches of a marine tertiary formation, called the Norwich Crag, hereafter to be described; thirdly, the freshwater beds already mentioned; and lastly, the drift. Immediately above the chalk, or crag, when that is present, is found here and there a buried forest, or a stratum in which the stools and roots of trees stand in their natural position, the trunks having been broken short off and imbedded with their branches and leaves. It is very remarkable that the strata of the overlying boulder formation have often undergone great derangement at points where the subjacent forest bed and chalk remain undisturbed. There are also cases where the upper portion of the boulder deposit has been greatly deranged, while the lower beds of the same have continued horizontal. Thus the annexed section (Fig. 104.) represents a cliff about 50 feet high, at the bottom of which is *till*, or unstratified clay, containing boulders, having an even horizontal surface, on which repose conformably beds of laminated clay and sand about 5 feet thick, which, in their turn, are succeeded by vertical, bent, and contorted layers of sand and loam 20 feet thick, the whole being covered by flint gravel. Now the curves of the variously colored beds of loose sand, loam, and pebbles are so complicated that not only may we sometimes find portions of them which maintain their verticality to a height of ten or fifteen feet, but they have also been folded upon themselves in such a manner that continuous layers might be thrice pierced in one perpendicular boring.

Fig. 104.



Cliff 50 feet high between Bacton Gap and Mundesley.

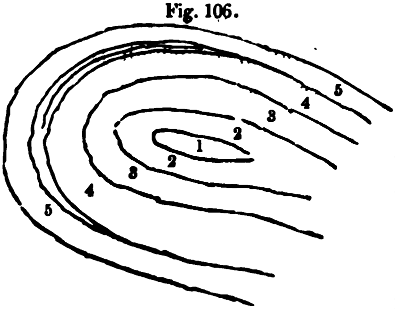
Fig. 105.



Folding of the strata between East and West Runton.

At some points there is an apparent folding of the beds round a central nucleus, as at *a*, Fig. 105., where the strata seem bent round a small mass of

Fig. 106.



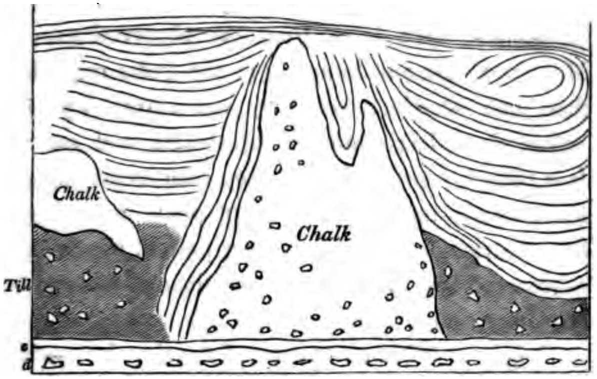
Section of concentric beds west of Cromer.

1. Blue clay. 3. Yellow sand.
2. White sand. 4. Striped loam and clay.
5. Laminated blue clay.

chalk; or, as in Fig. 106., where the blue clay, No. 1., is in the centre; and where the other strata, 2, 3, 4, 5, are coiled round it; the entire mass being twenty feet in perpendicular height. This appearance of concentric arrangement round a nucleus is, nevertheless, delusive, being produced by the intersection of beds bent into a convex shape; and that which seems the nucleus being, in fact, the innermost bed of the series, which has become partially visible by the removal of the protuberant portions of the outer layers.

To the north of Cromer are other fine illustrations of contorted drift reposing on a floor of chalk horizontally stratified and having a level surface. These phenomena, in themselves sufficiently difficult of explanation, are rendered still more anomalous by the occasional inclosure in the drift of huge fragments of chalk many yards in diameter. One striking instance occurs west of Sherringham, where an enormous pinnacle of chalk, between 70 and 80 feet in height, is flanked on both sides by vertical layers of loam, clay, and gravel. (Fig. 107.)

Fig. 107.



Included pinnacle of chalk at Old Hythe point, west of Sherringham.

This chalky fragment is only one of many detached masses which have been included in the drift, and forced along with it into their present position. The level surface of the chalk *in situ* (*d*) may be traced for miles along the coast, where it has escaped the violent movements to which the incumbent drift has been exposed.*

We are called upon, then, to explain how any force can have been exerted against the upper masses, so as to produce movements in which the subjacent strata have not participated. It may be answered that, if we conceive the till and its boulders to have been drifted to their present place by ice, a theory in support of which many arguments will presently be adduced, the lateral pressure may have been supplied by the stranding of ice islands. We learn, from the observations of Messrs. Dease and Simpson in the polar regions, that such islands, when they run aground, push before them large mounds of shingle and sand. It is therefore probable that they often cause great alterations in the arrangement of pliant and incoherent strata forming the upper part of shoals or submerged banks, the inferior portions of the same remaining unmoved.

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* For a full account of the drift of East Norfolk, see a paper by the author, Phil. Mag., No. 104., May, 1840.

Origin of Till and agency of floating ice. — If we call to mind the descriptions given of icebergs by those who have explored the arctic circle, we shall find reason to believe that the till above alluded to, with its boulders, is just such a mass as might be looked for wherever earth and stones have fallen to the bottom of the sea from melting ice. Thus, an account was given in the year 1822, by Scoresby, of icebergs seen by him drifting along in latitudes 69° and 70° N., which rose above the surface from 100 to 200 feet, and measured from a few yards to a mile in circumference. Many of them were loaded with beds of earth and rock, of such thickness that the weight was conjectured to be from 50,000 to 100,000 tons.*

A similar transportation of rocks is known to be in progress in the southern hemisphere. Thus an iceberg was encountered in 1839, in mid-ocean, in the antarctic regions, many hundred miles from any known land, sailing northwards, with a large erratic block firmly frozen into it.

The manner in which glaciers are formed in the mountainous regions of high latitudes, and become laden with mud and stones, will be mentioned in the next chapter. When they reach the sea, large masses become detached, and float off in the shape of icebergs. As these glaciers, when they fail to reach the sea-coast, leave at their extremity, wherever they melt away, a confused heap of unstratified rubbish, composed of mud and pieces of all the rocks with which they are loaded, so we may expect that the same kind of till may result from the liquefaction of icebergs in tranquil water. But, should the action of a current intervene at certain points or at certain seasons, then the materials will be sorted as they fall, and arranged in layers according to their relative weight and size. Hence there will be passages from till to stratified clay, gravel, and sand, and intercalations of one in the other.

It is not improbable, however, that a large portion of the Norfolk till may have resulted from the melting of barrier ice; for we find that, on some coasts of the antarctic regions, innumerable ice islands are drifted into bays by winds and currents, where they remain motionless, and, for the most part, aground, for months or years. One of these icy barriers, lately observed on Enderby's Land, is described as being from ten to fifteen miles broad, and fragments of a great variety of rocks were collected on it. The partial melting of such stationary ice might give rise to a deposit wholly distinct from any which can be formed by running water alone. For the solid materials, some angular and others rounded, and the accompanying mud, may have been derived partly from adjacent lands, and even in that case from the glaciers of many independent hydrographical basins, and partly from points very remote, producing a mixture of the most heterogeneous nature. Of such a character is the till or boulder clay, not only of Norfolk and Suffolk, but also of parts of the counties of Essex, Cambridge, Huntingdon, Bedford, Hertford, and Middlesex. We find dispersed irregularly through it many angular and rounded stones, from fossiliferous rocks older than the coal, and from the Silurian and carboniferous strata, and from the lias, oolite, chalk, and London clay, all with their peculiar fossils, together with trap, syenite, mica-schist, and other igneous and crystalline rocks. A fine example of this singular mixture may be seen almost in the suburbs of London, on the summit of Muswell Hill, near Highgate. Yet this deposit is partial, and is wanting in the Wealden district of Surrey, Kent, and Sussex. Perhaps it was only accumulated where the land was submerged during the epoch of floating ice; and this suggestion recalls to our consideration the buried forest already adverted to as underlying the drift on the coast of Norfolk. At the time when the trees grew there must have been dry land over a large area, which was afterwards submerged, so as to allow a mass of stratified and unstratified drift, 200 feet and more in thickness, to be superimposed. The encroachments of the sea in recent times enable us to demonstrate, beyond all doubt, the fact of this superposition, and that the forest was not formed along the present coast-line. Its situation implies a subsidence of several hundred feet since the commencement of the Post-Pliocene period, after which there must have been an upheaval of the same ground; for the forest bed of Norfolk is now again so high as to be exposed to view at many poins at low water; and this same upward movement may explain why the till, which is conceived to have been of submarine origin, is now met with far inland, and on the summit of hills.

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* Voyage in 1822, p. 233.

The boulder formation of the west of England, observed in Lancashire, Cheshire, Shropshire, Staffordshire, and Worcestershire, contains in some places marine shells of recent species, rising to various heights, from 100 to 350 feet above the sea. Here the erratics have come partly from the mountains of Cumberland, and partly from those of Scotland.

Boulder formation of Canada.—I shall conclude this chapter with remarking, that although the fossils of the European tertiary formations in general imply the former existence of warmer climates than those now experienced in the same latitudes, yet, at the close of the Pliocene and beginning of the Post-Pliocene periods, signs are not wanting in the northern hemisphere, both in Canada and Scotland, of the extension of an arctic climate further southwards than in our own times. Some localities in Scotland, where the phenomena have been observed, will be alluded to in the next chapter. Among those in Canada may be mentioned Beauport, and other points near Quebec, where strata of sand and clay have been found by Capt. Bayfield, containing an assemblage of fossil shells, which agree much more nearly with those now inhabiting the arctic regions than with the assemblage living at present in the Gulf of St. Lawrence. The individuals are in great abundance, but the species few, as in very high latitudes; and, what is almost equally characteristic of polar regions, the genera are almost as numerous as the species. It is remarkable that, although so few shells are now common to both sides of the Atlantic, these fossils are specifically identical, for the most part, with shells met with in strata at Uddevalla, and other places in Sweden and Norway, situated between the latitudes 58° and 60° north; those of Canada being in latitude 47° north, or the same parallel as the mouth of the Loire in France. The American formation attains at Beauport and elsewhere a height of 200 and 300 feet above the sea, and contains dispersed through the strata large boulders of granite, which could not have been propelled by a violent current, because the accompanying fragile shells are almost all entire. They seem, therefore, says Captain Bayfield, to have been dropped down from melting ice, like similar stones which are now annually deposited in the St. Lawrence.* In that river the loose ice accumulates on the shoals during winter, at which season the water is low. The separate fragments are readily frozen together in a climate where the temperature is sometimes 30° below zero, and boulders become entangled with them, so that in the spring, when the river rises, on the melting of the snow, the packs are floated off, frequently conveying away stones, several feet or even yards in diameter, to great distances. A single block of granite, 15 feet long, by 10 feet both in width and height, and which could not contain less than 1500 cubic feet of stone, was in this way moved down the river several hundred yards, during the late survey in 1837.* Heavy anchors of ships, lying on the shore, have, in like manner, been closed in and removed. In October, 1836, wooden stakes were driven several feet into the ground, at one point on the banks of the St. Lawrence, at high water mark, and over them were piled many boulders, as large as the united force of six men could roll. The year after, all the boulders had disappeared, and others had arrived, and the stakes had been drawn out and carried away by the ice.

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* Proceedings of Geol. Soc. No. 63. p. 119.

It is also ascertained, that ice-islands, detached far to the north, perhaps in Baffin's Bay, are brought by the current, in great numbers, down the coast of Labrador, every year, and are often carried through the straits of Bell Isle, between Newfoundland and the continent of America. These, after passing through the straits, sometimes float for several hundred miles to the southwest, up the Gulf of St. Lawrence, between the 40th and 50th degrees of N. latitude. In one of these icebergs, heaps of boulders and gravel were seen.

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* See a view of this and many accompanying boulders, Plate IV., Principles of Geology, 6th ed.

That stones are annually moved by ice in the Baltic, has long been known; and, very recently, on the shores of the Gulf of Finland, some large fragments were ascertained to have been carried many yards from the spot which they had previously occupied. When the fringe of ice which has encircled, during winter, the coast of the Gulf of Bothnia, and many parts of Sweden, Norway, and Denmark, breaks up, in spring, large stones, with small gravel and ice, all firmly frozen together on the beach, are floated away in detached masses.

In the beginning of this chapter, it was stated that in Russia and Northern Germany the erratics diminish in size in proportion as they are traced further from their source. The same observation holds true in regard to the average bulk of the Scandinavian boulders, when we pursue them southwards, from the south of Norway and Sweden through Denmark and Westphalia. This phenomenon is in perfect harmony with the theory of ice-islands floating in a sea of variable depth; for the heavier erratics require icebergs of a larger size to buoy them up; and, even when there are no stones frozen in, more than nine tenths of a mass of drift ice is under water. The greater, therefore, the volume of the iceberg, the sooner would it impinge on some shallower part of the sea; while the smaller and lighter floes, laden with finer mud and gravel, may pass freely over the same banks, and be carried to much greater distances. In embracing this opinion, however, we are not called upon to imagine that the northern sea was of small depth at the time of the transportation of large erratics,—a notion inconsistent with the great height at which some of them are found above its level. An iceberg 200 or 300 feet high would run aground in water more than 1000 feet deep; and Captain Ross found this to be the case in Baffin's Bay, where several were seen stranded in water 1500 feet deep.

CHAPTER XI.

BOULDER FORMATION CONTINUED, AND LOESS OF THE RHINE.

Signs of former extension of glaciers in the Alps — Moraines — Grooved and polished surface of rocks — Arrangement of Alpine erratics on the Jura — Whether transported by glaciers or floating ice — Recent transportation of erratics from the Andes to Chiloe — Till and erratics of Scotland — Ridges of till, sand, and gravel — Arctic character of fossils above the till on Clyde — Parts of the boulder deposit older than others — Whether the general climate of the globe was colder when the Scandinavian and Alpine drift was formed — Loess of the Rhine containing land shells — Its supposed connection with the melting of the Alpine glaciers.

It has long been a favorite conjecture with those who have speculated on the origin of the boulder deposit, that it was produced by a violent flood, or great oceanic wave from the north, the course of the Scandinavian blocks to Russia and Germany, and those of Canada to the United States, showing that they have travelled from higher to lower latitudes in distant parts of the northern hemisphere. It is scarcely necessary to point out to the reader how perfectly the genera. fact above mentioned is in accordance with the theory advanced in the last chapter, that floating ice has been mainly instrumental in the transport of erratics, inasmuch as the prevailing direction, both of icebergs and coast ice, is from polar to temperate latitudes.

The universality of large travelled fragments in all the countries bordering the Baltic, compared with their extreme rarity in those surrounding the Mediterranean, is another phenomenon confirmatory of the same views. It is also to be remarked, that true erratics are wanting in the equatorial parts of Asia, Africa, and America; whereas, when we cross the southern tropic, and reach Chili and Patagonia, we again encounter the boulder formation, between the latitude 41° S. and Cape Horn, with precisely the same characters which it assumes in Europe.

Alpine Erratics and Glaciers.—We have already seen that the ice of rivers, and that formed on coasts during winter, are very efficient as carrying powers; but the larger islands of ice which rise to the height of 200 or 300 feet above the surface, and which can only float in water of great depth, are neither formed on coasts nor in rivers, but are generated in inland valleys in the form of glaciers, which descend to the sea, and from which large portions break off and are drifted away by currents. Something, therefore, must be said in this place of glaciers; and, in treating of those in Switzerland, we shall be led on to the discussion of another question of high geological interest, namely, the peculiar manner in which erratics have been dispersed from that chain, as a centre, over the lower lands of Switzerland, Italy, Austria, and France.

In the year 1821, M. Venetz first announced his opinion that the Alpine glaciers must formerly have extended far beyond their present limits, and the proofs appealed to by him in confirmation of this doctrine were afterwards acknowledged by M. Charpentier, who strengthened them by new observations and arguments, and declared, in 1836, his conviction that the glaciers of the Alps must once have reached as far as the Jura, and have carried thither their moraines across the great valley of Switzerland. M. Agassiz, after several excursions in the Alps with M. Charpentier, and after devoting himself some years to the study of glaciers, published, in 1840, an admirable description of them, and of the marks which attest the former action of great masses of ice over the entire surface of the Alps, and the surrounding country.* From his researches, and those of his predecessors, we learn that the glaciers which fill the Alpine valleys have in summer a slow downward motion, which is partly due to gravitation, and partly to the dilatation of the mass during the freezing of water infiltered into pores and rents.

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* Agassiz, Études sur les Glaciers, of which an excellent analysis has been published in English by Mr. Maclaren.

The surface of the glacier is strewed over with gravel and stones detached from the surrounding precipices by frost, rain, lightning, or avalanches. Long lines of these stones, which settle on the sides of the glacier, are called the lateral moraines; while that found at the lower end of the ice is called the terminal moraine, a mass of earth and boulders, which it pushes before it when advancing, and leaves behind it when retreating; for when, in the Alps, a glacier reaches a lower and warmer situation, elevated about 3000 or 4000 feet above the sea, it melts so rapidly that, in spite of its downward movement, it can advance no further. Its precise limits are variable from year to year, and still more so from century to century; one example being on record, of a recession of half a mile in a single year. We also learn from M. Venetz, that whereas, between the eleventh and fifteenth centuries, all the Alpine glaciers were less advanced than now, they began in the seventeenth and eighteenth centuries to push forward so as to cover roads formerly open, and to overwhelm forests of ancient growth.

These oscillations enable the geologist to note the marks which they leave behind them as they retrograde, and among these the most prominent are the terminal moraines, or mounds of unstratified earth and stones, often divided by subsequent floods into hillocks, which cross the valley like ancient earth-works, or embankments made to dam up the river. Some of these transverse barriers were formerly pointed out by Saussure below the glacier of the Rhone, as proving how far it had once transgressed its present boundaries. On these moraines we see many large angular fragments, which, having been carried along on the surface of the ice, have not had their edges worn off by friction; but the greater number of the boulders, even those of large size, have been well rounded, not by the power of water, but by the mechanical force of the ice, which has pushed them against each other, or against the rocks flanking the valley. Others have fallen down the numerous fissures which intersect the glacier, where, being subject to the pressure of the whole mass of ice, they have been forced along, and either well rounded or ground down into sand, or even the finest mud, of which the moraine is largely constituted.

As the terminal moraines are the most prominent of all the monuments left by a receding glacier, so are they the most liable to obliteration; for violent floods or debacles are often occasioned in the Alps by the sudden bursting of what are called glacier-lakes. These temporary sheets of water are caused by the damming up of a river by a glacier which has increased during a succession of cold seasons, and, descending from a tributary into the main valley, has crossed it from side to side. On the failure of this icy barrier, the accumulated waters are let loose, which sweep away and level all transverse mounds of gravel and loose boulders below, and spread their materials in confused and irregular beds over the river-plain.

Another mark of the former action of glaciers, in situations where they exist no longer, is the polished, striated, or grooved surface of the rocks. The boulders, gravel, and sand, which lie underneath the glacier and are pushed along by it, sometimes adhere to the ice, and as the mass glides slowly along at the rate of a few inches, or at the utmost two or three feet, per day, they abrade, groove, and polish the rock, and the larger blocks are reciprocally grooved and polished by the rock on their lower sides. As the forces both of pressure and propulsion are enormous, the sand, acting like emery, polishes the surface; the pebbles, like coarse gravers, scratch and furrow it; and the large stones scoop out grooves in it.

Although the surface of almost every kind of rock, when exposed in the open air, wastes away by decomposition, yet some retain for ages their polished and furrowed exterior; and, if they are well protected by a covering of clay or turf, these marks of abrasion seem capable of enduring for ever. They have been traced in the Alps to great heights above the present glaciers, and to great horizontal distances beyond them.

There are also found, on the sides of the Swiss valleys, round and deep holes, with polished sides, such holes as waterfalls make in the solid rock, but in places remote from running waters, and where the form of the surface will not permit us to suppose that any cascade could ever have existed. Similar cavities are common in hard rocks, such as gneiss, in Sweden, where they are called *giant caldrons*, and are sometimes ten feet and more in depth; but in the Alps and Jura they often pass into spoon-shaped excavations and prolonged gutters. We learn from M. Agassiz that hollows of this form are now cut out by streams of water, which flow along the surface of glaciers, and then fall into fissures which are open to the bottom. Here, forming a cascade, the stream cuts a round cavity in the rock with the gravel and sand which it either finds there or carries down with it; and, as it usually happens that the glacier is advancing, a locomotive cascade is produced, which converts the first circular hole into a deep groove.

Another effect of a glacier is to lodge a ring of stones round the summit of a conical peak which may happen to project through the ice. If the glacier is lowered greatly by melting, these circles of large angular fragments, which are called "perched blocks," are left in a singular situation near the top of a steep hill or pinnacle, the lower parts of which may be destitute of boulders.

Alpine blocks on the Jura.—Now some or all the marks above enumerated,—the moraines, erratics, polished surfaces, striæ, caldrons, and perched rocks, are observed in the Alps at great heights above the present glaciers, and far below their actual extremities, also in the great valley of Switzerland, fifty miles broad, and almost everywhere on the Jura, a chain which lies to the north of this valley. The average height of the Jura is about one third that of the Alps, and is now entirely destitute of glaciers, yet it presents almost everywhere similar moraines, and the same polished and grooved surfaces, and water-worn cavities. The erratics, moreover, which cover it, present a phenomenon which has astonished and perplexed the geologist for more than half a century. No conclusion can be more incontestable than that these angular blocks of granite, gneiss, and other crystalline formations, came from the Alps, and that they have been brought for a distance of fifty miles and upwards across one of the widest and deepest valleys of the world, so that they are now lodged on the hills and valleys of a chain composed of limestone and other formations, altogether distinct from those of the Alps. Their great size and angularity, after a journey of so many leagues, has justly excited wonder; for hundreds of them are as large as cottages; and one in particular, celebrated under the name of Pierre à Bot, rests on the side of a hill about 900 feet above the lake of Neufchatel, and is no less than forty feet in diameter.

Von Buch, Escher, and Studer have shown, from an examination of the mineral composition of the boulders, that those on the western Jura, near Neufchatel, have come from the region of Mont Blanc and the Valais; those on the middle parts of the Jura from the Bernese Overland; and those on the eastern Jura from the Alps of the small cantons, Glaris, Schwytz, Uri, and Zug. The blocks, therefore, of these three great districts have been derived from parts of the Alps nearest to the localities in the Jura where we now find them, as if they had crossed the great valley in a direction at right angles to its length: the most western stream having followed the course of the Rhone, the central, that of the Aar, and the eastern, that of the two great rivers, Reuss and Limmat. The non-intermixture of these groups of travelled fragments, except near their confines, was always regarded as most enigmatical by those who adopted the opinion of Saussure, that they were all whirled along by a rapid current of muddy water rushing from the Alps.

M. Charpentier first suggested, as before mentioned, that the Swiss glaciers once reached continuously to the Jura, and conveyed to them these erratics; but at the same time he conceived that the Alps were formerly higher than now. M. Agassiz, on the other hand, instead of introducing distinct and separate glaciers, imagines that the whole valley of Switzerland was filled with ice, and that one great sheet of it extended from the Alps to the Jura, when the two chains were of the same height as now relatively to each other. Such an hypothesis labors under this difficulty, that the difference of altitude, when distributed over a space of fifty miles, gives a inclination of no more than two degrees, or far less than that of any known glaciers.

In the theory which I formerly advocated in the Principles of Geology, and which jointly with Mr. Darwin I have since endeavoured to render more complete, it was suggested that the erratics may have been transferred by floating ice to the Jura, at the time when the greater part of that chain, and the whole of the Swiss valley to the south, was under the sea. At that period the Alps may have attained only half their present altitude, and may yet have constitued a chain as lofty as the Chilian Andes, which, in a latitude corresponding to Switzerland, now send down glaciers to the head of every sound, from which icebergs, covered with blocks of granite, are floated seaward.* Opposite that part of Chili where the glaciers abound is situated the island of Chiloe, 100 miles in length, with a breadth of 30, running parallel to the continent. The channel which separates it from the mainland is of considerable depth, and twenty-five miles broad. Parts of its surface, like the adjacent coast of Chili, is overspread with recent marine shells, showing an upheaval of the land during a very modern period; and beneath these shells is a boulder deposit, in which Mr. Darwin found large travelled blocks. One group of fragments were of granite, which had evidently come from the Andes, while in another place angular blocks of syenite were met with. Their arrangement may have been due to successive crops of icebergs issuing from different sounds, to the heads of which glaciers descend from the Andes. These icebergs, taking their departure year after year from distinct points, may have been stranded repeatedly, in equally distinct groups, in bays or creeks of Chiloe, and on islets off the coast, so as afterwards to appear, some on hills and others in valleys, when that country and the bed of the adjacent sea had been upheaved. A continuance in future of the elevatory movement, in the region of the Andes and of Chiloe, might cause the former chain to rival the Alps in altitude, and give to Chiloe a height equal to that of the Jura.

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* Darwin's Journal, p. 283.

The same rise might dry up the channel between Chiloe and the mainland, so that it would then represent the great valley of Switzerland. In the course of these changes, all parts of Chiloe and the intervening strait, having in their turn been a sea-shore, may have been polished and scratched by innumerable icebergs running aground and grating on the bottom.

If we apply this hypothesis to Switzerland and the Jura, we are by no means precluded from the supposition that, in proportion as the land acquired additional height, and the bed of the sea emerged, the Jura itself may have had its glaciers; and those existing in the Alps, which had at first extended to the sea, may, during some part of the period of upheaval, have been prolonged much further into the valleys than now. At a later period, when the climate grew milder, these glaciers may have entirely disappeared from the Jura, and may have receded in the Alps to their present limits, leaving behind them in both districts those moraines which now attest the former extension of the ice.

It must be confessed, that our never having yet discovered marine shells of Recent or Pliocene species in the great valley of Switzerland or the Jura presents a formidable objection to the views above set forth, no marine tertiary strata newer than the Miocene having yet been detected between the Alps and Jura; and the shells and corals of the Miocene period implying a warmer climate than would seem compatible with the prevalence of so much ice in Europe.

Boulder deposit of Scotland. — On the other hand, daily experience teaches us to attach less and less importance to this kind of negative evidence in geology. Thus the like absence of organic remains has been remarked in the boulder formation, especially in the till, throughout Scotland; the only exceptions being the tusks and bones of the mammoth, found with a few marine shells in the till of Ayrshire. The same remark holds good in regard to the Scandinavian and Norfolk drift, although capable of preserving those fossils which are washed into it from older rocks. The rarity or entire want of fossil remains in these cases may be due to one or all of the following causes: First, as there are no shells in the moraines of glaciers, there will be none in the materials falling from melting icebergs; Secondly, as the stranding of ice-islands in the bays of Iceland since 1835 has driven away the fish for several successive seasons, and thereby caused a famine among the inhabitants of the coast, so we may presume that a sea habitually infested with melting ice, which would chill and *freshen* the water, might render the same uninhabitable by *marine* mollusca; Thirdly, parts of the boulder formation which are stratified are probably due to river-floods; and the gravel and sand brought down by these inundations would scarcely ever contain organic remains, or, if so, would be too porous to retain them.

When we endeavour to account for the boulder deposit of Scotland, we meet with many of the same difficulties as in Switzerland. Thus, for example, north of the Tay, in Forfarshire, we may compare the Grampians, rising to the height of 4000 feet and more, to the Alps; the valley of Strathmore to the Pays de Vaud, and the Sidlaw Hills to the Jura.* On the Sidlaw Hills we find large angular fragments of mica-schist, from 3 to 15 feet in diameter, at various heights; some ascending even to the highest summit, 1500 feet above the sea, and 15 miles distant from the nearest Grampian from which they could have been detached. In the large intervening vale of Strathmore, till, from 20 to 100 feet deep, and full of Grampian boulders, conceals almost everywhere the subjacent secondary rocks. If we then ascend into the region of the Grampians, we find in every glen longitudinal and frequently transverse mounds, like the lateral and terminal moraines of Swiss glaciers. The detritus in these mountains has everywhere a local character, and as we trace it downwards it becomes more complex in its composition, in proportion as it receives the contribution of a greater number of lateral glens.

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* See section, p. 103.

From these and other appearances, we may infer the probable existence of glaciers at that period when erratics were dispersed from the Grampians as from a centre over the surrounding regions. But in Scotland the submergence of the lower country, and the coöperation of floating ice, seem more indispensable than in the case of Switzerland; for the points from which the Grampian boulders have been conveyed are much lower, and those to which they have been carried equally remote. One fragment of mica-schist, weighing from 8 to 10 tons, has been pointed out by Mr. Maclaren as occurring at the height of 1100 feet above the sea on the Pentland Hills; the nearest mountain composed of this formation being 50 miles distant.*

In the valley of Strathmore, and other low grounds in Perthshire and Forfarshire, long ridges of till, capped with stratified sand and gravel, from 50 to 70 feet high, may be traced for many leagues, often resembling in form the lateral moraines of glaciers. As in the Norfolk drift, before described, the uppermost strata have been often bent and folded, as if by lateral pressure, while those below remain horizontal. Several ridges are sometimes seen parallel to each other; and they wind like rivers, sometimes inclosing oval and quadrangular spaces, in which are peat mosses and lakes containing shell-marl. As these mounds, having a steep talus on both sides, are not confined to Highland glens, but may be followed for great distances over level plains, they may, perhaps, mark the ancient course of one or more rivers during the glacial period, on the banks of which sand, pebbles, and boulders were heaped up during floods, as is now observed in some of the rivers in the north of Russia. Thus, on the Dwina, 80 miles above Archangel, M. M. Murchison and De Verneuil met with a ridge of large angular blocks of white limestone piled up on the river's edge, and about 20 or 30 feet above the stream. They ascertained that this great river was periodically subject to occasional extraordinary rises in the spring, and that, on those occasions, it bursts, and throws up upon its banks blocks of ice to heights of 20 or 30 feet above its ordinary level. In illustration of the same subject, Mr. Böttlingk, of Dorpat, mentions that when the floods subside in the rivers of Russian Finland, they sometimes leave large stones, which had been buoyed up by ice, entangled in the branches of fir trees, 40 feet above the ground. The muddy waters may also throw down layers of fine sediment on these same banks, and these may be frequently bent and forced into a vertical position by the pressure of sheets of ice, as above explained (p. 232.)

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* Geol. of Fife, &c., p. 220.

It was stated that the boulder deposit of Russia reposed on strata containing recent marine shells (p. 224.); but the till in Scotland rests immediately on the older rocks, and is covered by stratified sand and clay, which usually contain no fossils. At certain points, however, near the sea-coast, as, for example, in the estuaries of the Tay and Clyde, marine shells have been discovered in strata overlying the till. They occur on the Clyde at the height of 70 feet; but the deposit of which they form an integral part rises in the same country to an elevation of several hundred feet. Although between 80 and 90 per cent. are of recent species, the remainder are unknown; and even many which are recent now inhabit more northern seas, where we may hereafter hope to find living representatives of some of the unknown fossils. From the arctic character of this fauna, which resembles that of Quebec, before described, we may infer that these strata and the subjacent till are of higher antiquity than some parts of the boulder deposit of northern Europe. With respect, indeed, to the European drift and erratics in general, it is fair to presume that those parts of it are the most ancient which lie at present in regions most remote from existing glaciers and icebergs. The retreat of the ice from the fifty-fifth to the eightieth parallel of latitude, or from Scotland to Spitzbergen, may well have been the work of time; and, during a period of considerable duration, it is consistent with geological analogy to look for signs of fluctuations in the state of the animate world. Nevertheless, it is probable that the action of river-ice continued in Scotland long after that of icebergs and glaciers had ceased; we may at least infer that the ridges of sand and boulders, which have been described as inclosing the marl-lakes of Perthshire and Forfarshire, were referable to the Post-Pliocene period. For the fossils in the marl, whether they be the remains of plants, testacea, or quadrupeds, belong to recent species which now inhabit Scotland, or which, like the beaver, have been exterminated in historical times. These fossils are found to the very bottom of the deposit, and clearly indicate the fauna which began to exist the moment after the present configuration of the surface was completed.

Climate of the glacial period.—M. Agassiz imagines that the signs of glacial action, traceable throughout the Alps and northern Europe, imply a more intense cold in the general climate of the globe than that now prevailing. That the cold was greater in certain parts of Siberia, Europe, and North America, will not be disputed; but, before we can infer the universality of a colder climate, we must ascertain what was the condition of other parts of the northern, and of the whole southern, hemisphere at the time when the Scandinavian, British, and Alpine erratics were transported into their present position. It must not be forgotten that a great deposit of drift and erratic blocks is now in full progress of formation in the southern hemisphere, in a zone corresponding in latitude to the Baltic and to Northern Italy, Switzerland, France, and England. Should the uneven bed of the southern ocean be hereafter converted by upheaval into land, the hills and valleys will be strewed over with transported fragments, some derived from the antarctic continent, others from islands covered with glaciers, like S. Georgia, which must now be centres of the dispersion of drift, although situated in a latitude agreeing with that of the Cumberland mountains.

Not only are these operations going on between the 45th and 60th parallels of latitude south of the line, while the corresponding zone of Europe is free from ice; but, what is still more worthy of remark, we find in the southern hemisphere itself, only 900 miles distant from South Georgia, where the perpetual snow reaches to the sea-beach, lands covered with forests, as in Terra del Fuego. There is here no difference of latitude to account for the luxuriance of vegetation in one spot, and the absolute want of it in the other; but among other refrigerating causes in South Georgia may be enumerated the countless icebergs which float from the antarctic zone, and which chill as they melt the waters of the ocean, and the surrounding air, which they fill with dense fogs.

I have endeavoured in the "Principles of Geology" to point out the intimate connexion of climate with the state of the physical geography of the globe, and the dependence of the mean annual temperature, not only on the height of the dry land, but on its distribution in high or low latitudes at particular epochs. If, for example, at certain periods of the past, the antarctic land was less elevated and less extensive than now, while that at the north pole was higher and more continuous, the conditions of the northern and southern hemispheres might have been the reverse of what we now witness in regard to climate, although the mountains of Scandinavia, Scotland, and Switzerland may have been less elevated than at present. But, as it would require several chapters to do justice to this subject, I must refer the reader to the work alluded to for the theory of former vicissitudes in climate; and also for an explanation of the manner in which the bones of the mammoth and rhinoceros may have been buried by thousands in the frozen soil and drift of Siberia.

Loess of the valley of the Rhine.—Although we may withhold our assent to the theory that the erratic blocks of the Jura were conveyed from the Alps by ice moving on dry land, we must nevertheless admit that the Alpine glaciers once extended far beyond their present limits; and accordingly M. Agassiz has advanced the ingenious and not improbable conjecture that the loess of the Rhine, filled as it is with land and freshwater shells, may be referred to inundations caused by the melting and retreat of those great bodies of ice. This *loess*, as it is provincially termed in part of Germany, or *lehm*, as it is called in Alsace, consists chiefly of argillaceous matter combined with a sixth part of carbonate of lime, and a sixth of quartzose and micaceous sand. It is a pulverulent loam, of a dirty yellowish-gray color, often containing calcareous sandy concretions or nodules, rarely exceeding the size of a man's head. Its entire thickness amounts, in some places, to between 200 and 300 feet; yet there are often no signs of stratification in the mass, except here and there at the bottom, where there is occasionally a slight intermixture of drifted materials derived from subjacent rocks.

This finely comminuted mud is very similar to that now formed by the grinding down of stones beneath the weight of the moving glaciers, and the loess is precisely such a compound as the trituration of the micaceous tertiary sand called "molasse" would produce; a circumstance worthy of notice, as we may trace the loess continuously from the plains of the Rhine, below Cologne, up to the borders of Switzerland, until we enter the country occupied by the molasse, which the Alpine glaciers are supposed formerly to have reached. The deposit in question is very remarkable from its position, wide extent, and thickness, its homogeneous mineral character, and from its containing everywhere land and freshwater shells, without any intermixture of marine fossils. Its distribution clearly shows, that after the great valley of the Rhine, from Schaffhausen to Bonn, had acquired its present form, having its bottom strewed over with coarse gravel, a period arrived when it became filled up from side to side with fine mud, which was also poured from the Rhine into the valleys of its principal tributaries.

Thus, for example, it may be traced far into Würtemberg, up the valley of the Neckar; and from Frankfort, up the valley of the Main, to above Dettelbach. It is also spread over the country of Mayence, Eppelsheim, and Worms, on the left bank of the Rhine, and on the opposite side on the table land above the Bergstrasse, between Wiesloch and Bruchsal, where it attains a thickness of 200 feet. Near Strasburg, large masses of it are seen at the foot of the Vosges on the left bank, and at the base of the mountains of the Black Forest on the right bank. The Kaiserstuhl, a volcanic mountain which stands in the middle of the plain of the Rhine near Freiburg, has been covered almost everywhere with this loam, as have the extinct volcanos between Coblentz and Bonn. Near Andernach, in the Kirchweg, the loess containing the usual shells alternates with volcanic matter; and over the whole are strewed layers of pumice, lapilli, and volcanic sand, from 10 to 15 feet thick, very much resembling the ejections under which Pompeii lies buried. There is no passage at this upper junction from the loess into the pumiceous superstratum; and this last follows the slope of the hill, just as it would have done had it fallen in showers from the air on a declivity partly formed of loess.

But, in general, the loess overlies all the volcanic products, even those between Neuwied and Bonn, which have the most modern aspect; and it has filled up in part the crater of the Roderberg, an extinct volcano near Bonn. In 1833 a well was sunk at the bottom of this crater, through 70 feet of loess, in part of which were the usual calcareous concretions.

The interstratification above alluded to, of loess with layers of pumice and volcanic ashes, has led to the opinion that both during and since its deposition some of the last volcanic eruptions of the Lower Eifel have taken place. But as we must, in that case, assign a very modern date to these eruptions, this curious point deserves to be reconsidered; since it may possibly have happened that the waters of the Rhine, swollen by the melting of snow and ice, and flowing at a great height through a valley choked up with loess, may have swept away the loose superficial scoriæ and pumice of the Eifel volcanos, and spread them out occasionally over the yellow loam. Sometimes, also, the melting of snow on the slope of small volcanic cones may have given rise to local floods, capable of sweeping down light pumice into the adjacent low grounds.

The first idea which has occurred to most geologists, after examining the loess between Mayence and Basle, is, to imagine that a great lake once extended throughout the valley of the Rhine between those two places. Such a lake may have sent off large branches up the course of the Main, Neckar, and other tributary valleys, in all of which large patches of loess are now seen. The barrier of the lake might be placed somewhere in the narrow and picturesque gorge of the Rhine between Bingen and Bonn. But this theory is insufficient to explain the phenomena; for that gorge itself has once been filled with loess, which must have been tranquilly deposited in it, as also in the lateral valley of the Lahn, communicating with the gorge. The loess has also overspread the high adjoining platform, near the village of Plaidt above Andernach. Nay, on proceeding further down to the north, we discover that the hills which skirt the valley between Bonn and Cologne have loess on their flanks, which also covers here and there the gravel of the plain as far as Cologne.

Besides these objections to the lake theory, the loess is met with near Basle, capping hills more than 1200 feet above the sea; so that a barrier of land capable of separating the supposed lake from the ocean would require to be, at least, as high as the mountains called the Siebengebirge, near Bonn, the loftiest summit of which, the Oehlberg, is 1209 feet above the Rhine and 1369 feet above the sea. It would be necessary, moreover, to place this lofty barrier somewhere below Cologne, or precisely where the level of the land is now lowest.

Instead, therefore, of supposing one continuous lake of sufficient extent and depth to allow of the simultaneous accumulation of the loess, at various heights, throughout the whole area where it now occurs, I formerly suggested that, subsequently to the period when the countries now drained by the Rhine and its tributaries had nearly acquired their actual form and geographical features, they were again depressed gradually by a movement like that now in progress on the west coast of Greenland.* In proportion as the whole district was lowered, the general fall of the waters between the Alps and the ocean was lessened; and both the main and lateral valleys, becoming more subject to river inundations, were partially filled up with fluviatile silt, containing land and freshwater shells. When a thickness of many hundred feet of loess had been thrown down slowly by this operation, the whole region was once more upheaved gradually. During this upward movement most of the fine loam would be carried off by the denuding power of rains and rivers; and thus the original valleys might have been reëxcavated, and the country almost restored to its pristine state, with the exception of some masses and patches of loess such as still remain, and which, by their frequency and remarkable homogeneousness of composition and fossils, attest the ancient continuity and common origin of the whole. By imagining these oscillations of level, we might dispense with the necessity of erecting and afterwards removing a mountain barrier almost sufficiently high to exclude the ocean from the valley of the Rhine during the period of the accumulation of the loess.

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* Princ. of Geol. 5th and preceding editions.

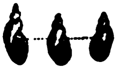
But, by adopting the glacial hypothesis, we escape from the necessity of assuming, not only the removal of a barrier, but also a great subsidence, followed by a reëlevation of the land, changes which, although consistent with the ordinary course of nature, are not as yet confirmed, in this case, by independent evidence. If we once admit the former existence of large masses of ice, stretching from the sources of the Rhine into the great valley of Switzerland, we cannot doubt that the liquefaction of the same might have given rise for centuries to annual inundations, and that the water would be densely charged with the most impalpable mud, derived from the moraines of the retreating glaciers. The bottoms of every inundated valley would gradually gain in height by fresh accessions of the fine sediment, until its thickness might amount to several hundred feet. But a time would at length arrive when, the supply of mud growing less, the waters, as they abated, would again hollow out the larger part of the original valley.

Besides the occasional proofs of successive accumulation afforded by interstratified gravel or volcanic matter, the calcareous concretions contained in the loess are sometimes arranged in horizontal layers. But the deposit exhibits for the most part no division into strata; and this characteristic of the loess must be attributed to the perfect homogeneousness of the matter thrown down from time to time, the whole mass having originated in one and the same region.

The proportion of land shells of the genera *Helix*, *Pupa*, and *Bulimus*, is very large in the loess; but in many places aquatic species of the genera

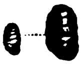
Limnea, *Paludina*, and *Planorbis* are also found. These may have been carried away during floods from shallow pools and marshes bordering the river, and the great extent of marshy ground caused by the wide overflowings of rivers above supposed would favor the multiplication of amphibious mollusks, such as the *Succinea* (Fig. 108.), which is almost everywhere characteristic of this formation, and is sometimes accompanied, as near Bonn, by another species *S. amphibia.* (Fig. 34.) Among other abundant fossils are *Helix plebeium* and *Pupa muscorum.* (See Figures.) Both the terrestrial and aquatic shells preserved in the loess are of most fragile and delicate structure, and yet they are almost invariably perfect and uninjured. They must have been broken to pieces had they been swept along by a violent inundation. Even the color of some of the land shells, as that of *Helix nemoralis*, is occasionally preserved.

Fig. 108.



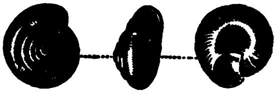
Succinea elongata.

Fig. 109.



Pupa muscorum.

Fig. 110.



Helix plebeium.

Bones of vertebrated animals are rare in the loess, but those of the mammoth, horse, and some other quadrupeds have been met with. At the village of Binningen, and the hills called Bruder Holtz, near Basle, I found the vertebræ of fish, together with the usual shells. These vertebræ, according to M. Agassiz, belong decidedly to the Shark family, perhaps to the genus *Lamna*. In explanation of their occurrence among land and freshwater shells, it may be stated that certain fish of this family ascend the Senegal, Amazon, and other great rivers, to the distance of several hundred miles from the ocean.*

If the views above proposed respecting the origin of the loess be correct, we should expect to see analogous deposits along the course of other great rivers descending from the Alps; and accordingly such a deposit is said to occur on the banks of the Danube, as far as Hungary.

All the shells in the loess of the Rhine are of recent European species, so that the gradual filling up and reëxcavation of the valleys of one of the largest hydrographical basins of Europe, an operation which must have consumed a long period of time, belongs to the modern or Post-Pliocene era; and the recession of the Alpine glaciers was, consistently with the hypothesis before suggested, a contemporaneous event.

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* Proceedings Geol. Soc. No. 43. p. 222.

CHAPTER XII.

CLASSIFICATION OF TERTIARY FORMATIONS.

First discovery of tertiary strata — Detached formations scattered over Europe — Strata of Paris and London — More modern groups — General principles of classification — Peculiar difficulties in determining the chronology of tertiary groups — Increasing proportion of living species of shells in strata of newer origin — Terms Eocene, Miocene, and Pliocene — Percentage of recent species in the tertiary formations of Great Britain — Changes of climate at successive periods.

We come now to the consideration of a class of fossiliferous formations, called "tertiary" which are immediately antecedent in the order of time to the Post-Pliocene deposits already treated of. The name of tertiary has been given to them, because they are all posterior in date to the rocks termed "secondary," of which the chalk constitutes the newest group.

Patches of tertiary strata, some of freshwater, others of marine origin, have been observed in various parts of Europe, their geographical extent being usually small as compared to the secondary formations, and their position often suggesting the idea of their having been deposited in different bays, lakes, estuaries, or inland seas, after a large portion of the European area had already been converted into dry land. They all agree in containing organic remains, which make upon the whole a nearer approach to the generic and specific types of the living creation, than do the fossils of the secondary rocks.

The first series of tertiary deposits of which the characters were accurately determined, were those occurring in the neighbourhood of Paris, first described by MM. Cuvier and Brongniart. They were ascertained to consist of successive sets of strata, some of marine, others of freshwater origin lying one upon the other. The fossil shells and corals were perceived to be almost all of unknown species, and to have in general a near affinity to those now inhabiting warmer seas. The bones and skeletons of land animals, some of them of large size, and belonging to more than forty distinct species, were examined by Cuvier, and declared by him not to agree with any hitherto observed in the living creation.

Strata were soon afterwards brought to light in the vicinity of London, and in Hampshire, which, although dissimilar in mineral composition were justly inferred by Mr. T. Webster to be of the same age as those of Paris, because the greater number of the shells were specifically identical. For the same reason rocks found on the Gironde, in the South of France, and at certain points in the North of Italy, were suspected to be of contemporaneous origin.

A variety of deposits were afterwards found in other parts of Europe, all reposing immediately on rocks as old, or older than the chalk, and which bore a general resemblance in their organic remains to those previously observed near Paris and London. An attempt was therefore made at first to refer the whole to one period; and when at length this seemed impracticable, it was contended that as in the Parisian series there were many subordinate formations of considerable thickness which must have accumulated one after the other, during a great lapse of time, so the newly found patches of tertiary strata scattered over Europe might correspond in age, some of them to the older, and others to the newer, subdivisions of the Parisian series.

This error, although almost unavoidable on the part of those who made the first generalizations in this branch of geology, retarded seriously for some years the progress of classification. A more scrupulous attention to specific distinctions aided by a careful regard to the relative position of the strata containing them, led at length to the conviction that there were formations both marine and freshwater of various ages, and all newer than the strata of Paris and London.

One of the first steps in this chronological reform was made in 1811, by an English naturalist, Mr. Parkinson, who pointed out the fact that certain shelly strata, provincially termed "Crag" in Suffolk, lay decidedly over a deposit which was the continuation of the blue clay of London. At the same time he remarked that the fossil testacea in these newer beds were not only distinct from those of the blue clay, but were many of them identical with species now inhabiting the neighbouring sea.

Another important discovery was soon afterwards made by Brocchi in Italy, who investigated the argillaceous and sandy deposits replete with shells which form a low range of hills, flanking the Apennines on both sides, from the plains of the Po to Calabria. These lower hills were called by him the Subapennines, and they contained in truth strata of very different ages, comprising even some beds which have been termed Post-Pliocene in the ninth chapter, but all were newer than those of Paris and London. In Brocchi's opinion about half the species of Subapennine shells agreed with those now living in the sea, an average result obtained from the fossils of the various members of the series which he had blended together.

Another tertiary group occurring in the neighbourhood of Bordeaux and Dax, in the South of France, was examined by M. de Basterot in 1825, who described and figured several hundred species of shells, which differed for the most part both from the Parisian series and those of the Subapennine hills. It was soon, therefore, suspected that this fauna might belong to a period intermediate between that of the Parisian and Subapennine strata, and it was not long before the evidence of superposition was brought to bear in support of this opinion, for other strata, contemporaneous with those of Bordeaux, were observed in one district to overlie the Parisian formation, and in another to underlie the Subapennine beds. An example of the former kind was pointed out in 1829 by M. Desnoyers, who ascertained that the sand and marl of marine origin called Faluns, near Tours, in the basin of the Loire, rested upon a lacustrine formation, which constitutes the uppermost subdivision of the Parisian group, extending continuously throughout a great table land intervening between the basin of the Seine and that of the Loire. These overlying strata, full of sea-shells and corals, M. Desnoyers assimilated in age to the Crag of Suffolk, before mentioned.* The other example occurs in Piedmont, where strata, containing many fossils similar to those of Bordeaux, were observed by Bonelli and others in the environs of Turin, subjacent to strata belonging to the Subapennine group of Brocchi.

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* See chap. XIV.

Without pretending to give a complete sketch of the progress of discovery, I may refer to the facts above enumerated, as illustrating the course usually pursued by geologists when they attempt to found new chronological divisions. The method bears some analogy to that pursued by the naturalist in the construction of genera, when he selects a typical species, and then classes all other species of animals and plants which agree with this standard within certain limits as congeners. The genera A. and C. having been founded on these principles, a new species is afterwards met with, departing widely both from A. and C., but in many respects of an intermediate character. For this new type it becomes necessary to institute the new genus B., in which are included all species afterwards brought to light, which agree more nearly with B. than with the types of A. or C. In like manner a new formation is met with in geology, and the characters of its fossil fauna and flora investigated. From that moment it is considered as a record of a certain period of the earth's history, and a standard to which other deposits may be compared; and if they occupy the same relative position, and contain the same or nearly the same organic remains, they are regarded in the light of contemporary annals. All such monuments are said to relate to one period, during which certain events occurred, such as the formation of particular rocks by aqueous or volcanic agency, or the continued existence and fossilization of certain tribes of animals and plants. When several of these periods have had their true places assigned to them in a chronological series, others may be discovered which it may be necessary to intercalate between those first known; and the difficulty of assigning clear lines of separation must increase in proportion as chasms in the past history of the globe are filled up.

Every zoologist and botanist is aware that it is a comparatively easy task to establish genera in departments which have been enriched with only a small number of species, and where there is as yet no tendency in one set of characters to pass almost insensibly, by a multitude of connecting links, into another. They also know that the difficulty of classification augments, and that the artificial nature of their divisions becomes more apparent in proportion to the increased number of objects brought to light. But in separating families and genera, they have no other alternative than to avail themselves of such breaks as still remain, or of every hiatus in the chain of animated beings which is not yet filled up. So in geology, we may be eventually compelled to resort to sections of time as arbitrary, and as purely conventional, as those which divide the history of human events into centuries. But in the present state of our knowledge, it is more convenient to use the interruptions which still occur in the regular sequence of geological monuments, as boundary lines between our principal groups or periods.

The isolated position of distinct tertiary deposits in different parts of Europe has been already alluded to. In addition to the difficulty presented by this want of continuity when we endeavour to settle the chronological relations of these deposits, another arises from the frequent dissimilarity in mineral character of strata of contemporaneous date, such, for example, as those of London and Paris before mentioned. The identity or non-identity of species is also a criterion which often fails us. For this we might have been prepared, for we have already seen, that the Mediterranean and Red Sea, although so near each other, have each their peculiar fauna, and a considerable difference is found in the four groups of testacea now living in the Baltic, English Channel, Black Sea, and Mediterranean, although all these seas have some species in common. In like manner the diversity of the fossils of different tertiary formations, which have been thrown down in distinct seas, estuaries, bays, and lakes, does not always imply a distinctness in the times when they were produced, but may have arisen from climate and conditions of physical geography wholly independent of time. On the other hand, it is perfectly clear, that different sets of tertiary strata immediately superimposed upon each other, contain distinct imbedded species of fossils, in consequence of fluctuations which have been going on in the animate creation, and by which in the course of ages one state of things in the organic world has been substituted for another wholly dissimilar. It has also been shown that in proportion as the age of a tertiary deposit is more modern, so is its fauna more analogous to that now in being in the neighbouring seas. It is this law of a nearer agreement of the fossil testacea with the species now living, which may often furnish us with a clue for the chronological arrangement of scattered deposits, where we cannot avail ourselves of any one of the three ordinary chronological tests; namely, superposition, mineral character, and the specific indentity of the fossils.

Thus, for example, on the African border of the Red Sea, a white calcareous formation has been observed, containing several hundred species of shells differing from those found in the clay and volcanic tuff of Ischia, near Naples. Another deposit has been found at Uddevalla, in Sweden, in which a large portion of the shells do not agree with those of Ischia. But although in these three cases there may be scarcely a single shell common to the different formations, we do not hesitate to refer them all to one period. (the Post-Pliocene,) because the species agree in every instance with those now living in the contiguous seas. In like manner, when we have discovered a limestone in Sicily, rising to the height of 3000 feet, in which more than four fifths of the shells are the same as those of the Mediterranean, we may regard such a deposit as contemporaneous with other strata on the Clyde in Scotland, in which all the shells, with the exception of fifteen in a hundred, are of living northern species. In both these cases, the assemblage of fossils exhibits a corresponding amount of divergence from the existing state of things. The advantage of the test here pointed out consists in supplying us with a common point of departure in all countries however remote; and when we find, that in North America there are tertiary strata in which, like those of Paris and London, more than 95 per cent. of the fossil shells differ from any now living, we may presume that these may be of nearly the same relative antiquity.

It must, however, be admitted, that the further we recede from the present times, and the smaller the relative number of recent as compared with extinct species in the tertiary deposits, the less confidence can we place in the exact value of this test, especially when comparing the strata of remote regions; for we cannot presume that the rate of former alterations in the animate world, or the continual going out and coming in of species, has been everywhere equal in equal quantities of time. The form of the land and sea, and the climate, may have changed more in one region than in another; and consequently there may have been a greater destruction and renovation of species in one part of the globe than elsewhere. But although these considerations should put us on our guard against relying too implicitly on the accuracy of this test, yet it can never fail to throw great light on the chronological relations of tertiary groups with each other, and the connexion of their fossils with the existing state of the organic world.

Many authors have divided the European tertiary strata into three groups, — lower, middle, and upper; the lower comprising the oldest formations of Paris and London before-mentioned; the middle those of Bordeaux and Touraine; and the upper all those newer than the middle group.

When engaged in 1828 in preparing my work on the Principles of Geology, I conceived the idea of classing the whole series of tertiary strata in four groups, and endeavouring to find characters for each, expressive of their different degrees of affinity to the living fauna. With this view, I obtained information respecting the specific identity of many tertiary and recent shells from several Italian naturalists, and among others from Professors Bonelli, Guidotti, and Costa. Having in 1829 become acquainted with M. Deshayes, of Paris, already well know by his conchological works, I learnt from him that he had arrived, by independent researches, and by the study of a large collection of fossil and recent shells, at very similar views respecting the arrangement of tertiary formations. At my request he drew up, in a tabular form, lists of all the shells known to him to occur both in some tertiary formation and in a living state, for the express purpose of ascertaining the proportional number of fossil species identical with the recent which characterized successive groups; and this table was published by me in 1833.* The number of tertiary fossil shells examined by M. Deshayes was about 3000; and the recent species with which they had been compared, about 5000. The result then arrived at was, that in the lower tertiary strata, or those of London and Paris, there were about 3½ per cent. of species identical with recent; in the middle tertiary of the Loire and Gironde about 17 per cent.; and in the upper tertiary or Subapennine beds, from 35 to 50 per cent. In formations still more modern, some of which I had particularly studied in Sicily, where they attain a vast thickness and elevation above the sea, the number of species identical with those now living was believed to be from 90 to 95 per cent. For the sake of clearness and brevity, I proposed to give short technical names to these four groups, or the periods to which they respectively belonged. I called the first or oldest of them Eocene, the second Miocene, the third Older Pliocene, and the last or fourth Newer Pliocene. The first of the above terms, Eocene, is derived from ηως, eos, *dawn*, and καινος, cainos, *recent*, because the fossil shells of this period contain an extremely small proportion of living species, which may be looked upon as indicating the dawn of the existing state of the testaceous fauna, no recent species having been detected in the older or secondary rocks.

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* See Princ. of Geol. vol. iii., 1st ed.

The term Miocene (from μειον, meion, *less*, and καινος, cainos, *recent*,) is intended to express a minor proportion of recent species; the term Pliocene (from πλειον, pleion, *more*, and καινος, cainos, *recent*,) a comparative plurality of the same. It may assist the memory of students to remind them, that the *Mi*ocene contain a *mi*nor proportion, and *Pl*iocene a comparative *pl*urality of recent species; and that the greater number of recent species always implies the more modern origin of the strata.

The distribution of the fossil species from which the results before mentioned were obtained in 1830 by M. Deshayes was as follows: —

In the formations of the Pliocene periods, older and newer	777
In the Miocene	1021
In the Eocene	1238
	3036

Since the year 1830 the progress of conchological science has been most rapid, and the number of living species obtained from different parts of the globe has been raised from about 5000 to more than 10,000. New fossil species have also been added to our collections in great abundance; and at the same time a more copious supply of individuals both of fossil and recent species, some of which were previously very rare, have been procured, affording more ample data for determining the specific character. Besides the reforms introduced in consequence of these new zoological facilities, other errors of a geological nature have been in many instances removed. Thus, for example, the fossils of more than one member of the tertiary series occurring in the same district, had occasionally been confounded together, as in the case of the Crag of Norfolk and Suffolk, afterwards to be mentioned*; and these being now separated, the shells belonging respectively to each division exhibit a very different relation to the existing fauna from the mean result previously obtained.

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* See chap. XIV.

Many years must be devoted to the study of the European tertiary formations before a complete revision can be effected in their chronological arrangement, due regard being paid to the proportional number of recent species contained in each. It need scarcely be remarked, that numerical estimates such as those now alluded to, must be more vague in regions where we are imperfectly acquainted with the shells of the neighbouring sea, as in the case of the Mediterranean, than where we are much further advanced in our knowledge, as with respect to the testaceous fauna of the British Isles. The comparison, therefore, of the fossils of several of our English tertiary formations with the known recent shells is highly interesting, and the contrast which is afforded by the results is sufficiently striking, as the following table will show.

Periods.	Localities, &c.	Percentage of recent.	Number of Fossils compared.
Post-Pliocene	Freshwater of valley of the Thames	99 to 100	40
Newer Pliocene	Marine strata near Glasgow	85 to 90	160
Older Pliocene	Norwich Crag	60 to 70	111
Miocene	Suffolk, red and coralline Crag	20 to 30	450
Eocene	London & Hampshire	1 or 2	400

The deposits enumerated in the above list will be treated of in the sequel, and I shall point out some of the continental groups which may agree in age with those of England, and others which may probably require to be intercalated as referable to periods intermediate in date between those of which we happen to possess monuments in our own country.

It has long been a received opinion, that the more ancient the tertiary strata, the more nearly do the fossil testacea approach in their generic forms, and in the number of species, to the shells of warmer and tropical seas; so that in central and southern Europe, the climate of the Eocene period appears to have been nearly tropical, that of the Miocene sub-tropical, an opinion which is not only borne out by the shells, but, to a certain extent, by the corals, reptiles, and fish. The climate of the Pliocene formations resembled more nearly that now prevailing in correspoding latitudes;— but in some of the newer Pliocene and Post-Pliocene strata of the north of Europe and Canada, there are indications, as before observed,* of a fauna more arctic than that now inhabiting the same regions.

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* See p. 236.

CHAPTER XIII.

NEWER AND OLDER PLIOCENE FORMATIONS.

Freshwater deposits in valley of Thames — Comparative longevity of species in the mammalia and testacea — Strata near Glasgow — Madeira — Newer Pliocene formations largely developed in Sicily — Limestone of great thickness and elevation — Alternation of marine and volcanic formations — Proofs of slow accumulation — Great geographical changes in Sicily since the living fauna and flora began to exist — Older Pliocene strata — Norwich Crag — Subapennine beds — Asti, Sienna, Rome — Osseous breccias and cavern deposits—Sicily — Kirkdale — Origin of stalactite — Australian cave-breccias — Teeth of fossil quadrupeds.

At several points in the valley of the Thames, as at Brentford, Ilford, Grays, and Erith, a freshwater deposit occurs, consisting of horizontal strata of loam, sand, and gravel, from 20 to 60 feet thick. More than 40 species of terrestrial and freshwater shells derived from these and similar deposits on the banks of the Stour and Medway, appear to be identical with species now living in Britain, with the exception of three, namely, *Paludina marginata* (Fig. 102.), *Unio littoralis* (Fig. 29.), now living in the Loire, and *Cyrena trigonula* (Fig. 26.). The fossil last mentioned is abundant, and deserves notice, because the genus

Cyrena is no longer European. Some conchologists, however, regard the species as identical with the Egyptian shell, *C. consobrina*, now living in the Nile.

Bones both of herbiverous and carnivorous mammalia are also contained in these freshwater strata. The elephant, or mammoth, is particularly abundant, as are the ox, deer, and horse. An extinct species of rhinoceros (see Fig. 122.), and hippopotamus have been also found, and still more rarely the bear, hyæna, and tiger.*

The student has here a good exemplification of the manner in which the fossils of the more modern formations, when traced back retrospectively, first begin to diverge from the recent type. A small intermixture of exotic species is recognised, and some doubts are entertained by the naturalist respecting the perfect identity of one or two fossil with recent species. At the same time the mammalia are in part extinct, and partly identical with those now inhabiting the country.

The phenomenon last mentioned and which was before alluded to (p. 214.), is by no means confined to Europe, for Mr. Darwin found at Bahia Blanca, in South America, lat. 39° S. near the northern confines of Patagonia, fossil remains of the extinct mammiferous genera Megatherium, Megalonyx, Toxodon, and others, associated with marine shells, almost all of species already ascertained to be still living in the contiguous sea.*

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* Morris, Mag. of Nat. Hist. 1838, p. 539.

It was before hinted (p. 214.), that the longevity of species in the testacea appears by geological evidence to have exceeded that of the mammalia, the latter being probably endowed with less capacity for enduring those changes of climate and other external circumstances which take place in the course of ages on the earth's surface.

The above remarks will show that the fresh-water formations of the basin of the Thames, if not referable to the Post-Pliocene period, belong to the close of the era immediately antecedent, and they afford a good illustration of the shades by which the newer Pliocene formations pass insensibly into others more modern, which in their turn blend as we have seen with those of the human or historical times.

I have already alluded to certain marine strata overlying till near Glasgow, and at other points on the Clyde, in which the shells are for the most part British, with an intermixture of some arctic species, and others, about a tenth or more of the whole, supposed to be extinct. (See p. 257.) This formation may also be called Newer Pliocene.

Madeira. — The soil and subsoil of the island of Madeira, affords a good exemplification of a fossil fauna, making a slight departure from that now existing on the same spot, as it is filled for a great depth with land shells, one sixth of which are of extinct species, the others still living on the island. At one point a mass of pumice or volcanic tuff has been showered down on this deposit, or has been washed over it by a land flood.*

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* Zool. of Beagle, part 1. pp. 9. 111.

Sicily.—In no part of Europe are the newer Pliocene formations seen to enter so largely into the structure of the earth's crust, or to rise to such heights above the level of the sea, as in Sicily. They cover nearly half the island, and near its centre, at Castrogiovanni, they reach an elevation of 3000 feet. They consist principally of two divisions, the upper calcareous, the lower argillaceous, both of which may be seen at Syracuse, Girgenti, and Castrogiovanni.

A great variety of shells have been found at Palermo in this formation, and it has been remarked by Dr. Philippi, to whom we are indebted for the best work on the tertiary fossils of this island, that about one fifth of the species differ from those now known to exist in the Mediterranean, whereas the strata in Ischia, before alluded to, and others at the base of Etna and at Cape

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* J. Smith, Esq. Proceedings Geol. Soc. No. 73.

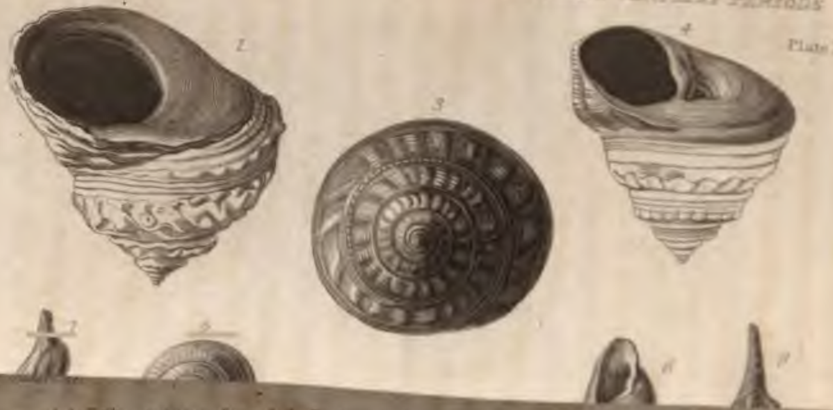
Melazzo are more modern, the fossils agreeing entirely with the present Mediterranean fauna. As the shells from all these Sicilian beds, whether Post-Pliocene or older, have generally been confounded together, I have no doubt that the proportion of 95 per cent. of recent species, given me by M. Deshayes, in 1828, is higher than he would have deduced from the fossils of the Pliocene beds of Sicily considered separately.

I have lately examined with scrupulous care, and with the assistance of Mr. G. Sowerby, 303 species brought from these newer Pliocene beds, and we found that 73 of them could not be identified with any living species from the Mediterranean, which gives a proportion of more than a fifth unknown. But, on the other hand, it should be remarked, that only 536 recent Mediterranean shells were known to Philippi, and Mr. Sowerby was only able to refer to 550 in the cabinets in London, a number which we may fairly presume to be part only of the existing fauna of the Mediterranean. For we may safely assume from the geographical position of this sea, the temperature of its waters, and the richness of its littoral fauna, that it is inhabited by a greater number of testacea than the British seas, which have already yielded 600 species. The proportion, therefore, of extinct or unknown fossils may hereafter be reduced to 10 or 15 per cent., in

FOSSIL SHELLS

PLIOCENE TERTIARY PERIODS

Plate 1.



1.2 Turbo rugosus Lin. _ 3.4 Trochus magus Lin. _ 5 Solarium variegatum Lam.ᵏ 6 Tornatella fasciata Lam.ᵏ _ 7 Pleurotoma vulpecula Broc. _ 8 Fusus crispus Borr. 9 Buccinum prismaticum Broc. _ 10 Pleurotoma rotata Broc. _ 11 Buccinum semistriatum Broc. _ 12 Mitra plicatula Broc. _ 13 Cassidaria echinophora Lam.ᵏ _ 14 Cytherea rugosa Lam.ᵏ var.

London. Published by John Murray, Jan.ʸ 1841 which list we may expect to find those species, such as *Buccinum prismaticum*, *B. semistriatum*, *Pleurotoma rotata*, *Fusus crispus*, and *Mitra plicatula* (See Pl. 1. Figs. 7, 8, 9. 11, and 12.), which are common to Sicily and the older Subapennine beds of Italy.

If, then, we feel at liberty to assume that between 80 and 90 per cent. of the Sicilian fossil shells are of species still living, this conclusion will naturally seem astonishing to all who are accustomed in the north of Europe to see the more modern deposits attaining an insignificant thickness, and almost always soft and incoherent in texture.

The newer Pliocene rocks of Sicily rest immediately and in conformable stratification on secondary marls and clays, some of which are celebrated for containing gypsum, salt, and sulphur in abundance. These last have been shown by Hoffmann to agree nearly in age with the English chalk.*

The upper or calcareous member of the newer Pliocene group before mentioned consists, in some places, of a yellowish-white stone, like the calcaire grossier of Paris, in others, of a rock nearly as compact as marble. Its aggregate thickness amounts sometimes to 700 or 800 feet. It usually occurs in regular horizontal beds, and is occasionally intersected by deep valleys, such as those of Sortino and Pentalica, in which are numerous caverns. The fossils are in every stage of preservation, from shells retaining portions of their animal matter and color, to others which are mere casts.

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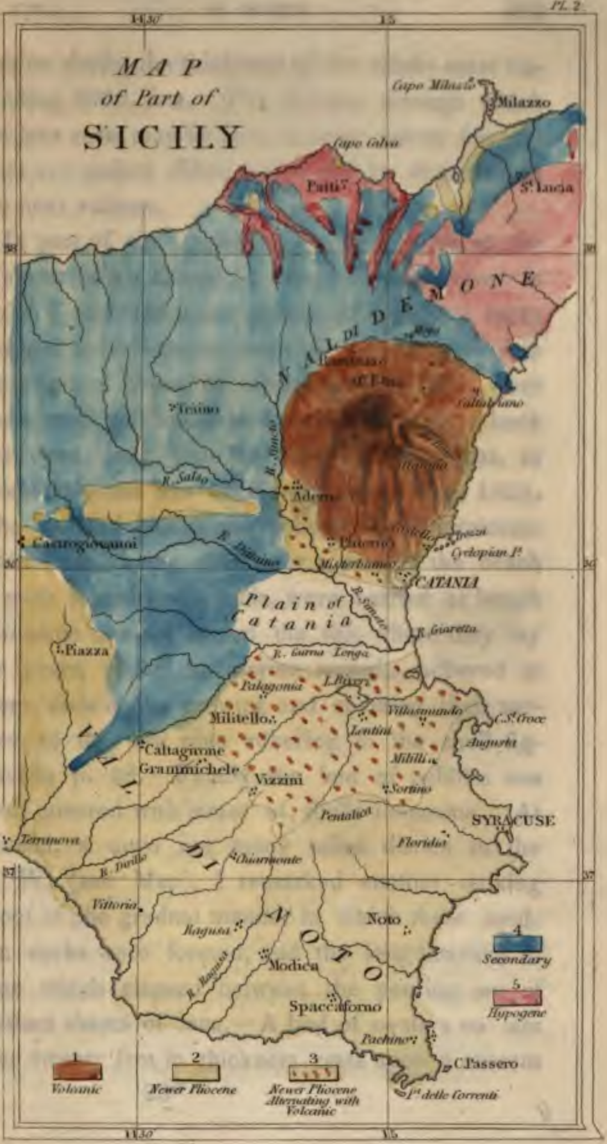
* See the posthumous work of Hoffmann, whose excellent account of the geology of Sicily is accompanied by a map, which has enabled me to correct and improve that of the eastern half of the island, formerly given in the Principles of Geology, and now republished, (see Pl. 2.)

The limestone passes downwards into a sandstone and conglomerate, below which is clay and blue marl, like that of the Subapennine hills, from which perfect shells and corals may be disengaged. The clay sometimes alternates with yellow sand.

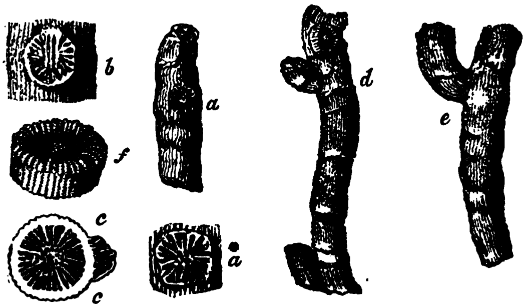
In the annexed map it will be seen, that south of the plain of Catania is a region in which the tertiary beds are intermixed with volcanic matter, which has been for the most part the product of submarine eruptions. It appears that, while the clay, sand, and yellow limestone before mentioned, were in course of deposition at the bottom of the sea, volcanos burst out beneath the waters, like that of Graham island, in 1831, and these explosions recurred again and again at distant intervals of time. Volcanic ashes and sand were showered down and spread by the waves and currents so as to form strata of tuff, which are found intercalated between beds of limestone and clay containing


Pl. 2
14.30
15
38
37
MAP
of Part of
SICILY
Capo Milazzo
Milazzo
Capo Calva
Patti
St. Lucia
VAL DI DEMONE
Randazzo
Mt. Etna
Traino
R. Simeto
R. Salso
Aderno
Castrogiovanni
R. Dittaino
Paterno
Misterbianco
Cyclopian I.
CATANIA
Plain of Catania
R. Simeto
R. Giaretta
R. Gurna Longa
Piazza
Palagonia
L. Biviere
Militello
Villasmundo
C. St. Croce
Lentini
Augusta
Caltagirone
Grammichele
Melilli
Vizzini
Sortino
Pentalica
SYRACUSE
Terranova
Floridia
R. Dirillo
Chiaramonte
VAL DI NOTO
Vittoria
Noto
Ragusa
R. Ragusa
Modica
Spaccaforno
Pachino
C. Passero
Pt. delle Correnti
1 Volcanic
2 Newer Pliocene
3 Newer Pliocene Alternating with Volcanic
4 Secondary
5 Hypogene

marine shells, the thickness of the whole mass exceeding 2000 feet. The fissures through which the lava rose may be seen in many places forming what are called *dikes*, which will be described in the next volume.

In part of the region above alluded to, as, for example, near Lentini, a conglomerate occurs in which I observed many pebbles of volcanic rocks covered by full-grown *serpulæ*. We may explain the origin of these by supposing that there were some small volcanic islands which may have been destroyed from time to time by the waves, as Graham Island has been swept away since 1831. The rounded blocks and pebbles of solid volcanic matter, after being rolled for a time on the beach of such temporary islands, were carried at length into some tranquil part of the sea, where they lay for years, while the marine *serpulæ* adhered to them, their shells growing and covering their surface, as they are seen adhering to the shell figured in p. 48. Finally, the bed of pebbles was itself covered with strata of shelly limestone. At Vizzini, a town not many miles distant to the S. W. (see Map), I remarked another striking proof of the gradual manner in which these modern rocks were formed, and the long intervals of time which elapsed between the pouring out of distinct sheets of lava. A bed of oysters no less than twenty feet in thickness rests upon a current of basaltic lava. The oysters are perfectly identifiable with our common eatable species. Upon the oyster bed, again, is superimposed a second mass of lava, together with tuff or peperino. In the midst of the same alternating igneous and aqueous formations is seen near Galieri, not far from Vizzini, a horizontal bed, about a foot and a half in thickness, composed entirely of a common Mediterranean coral (*Caryophyllia cespitosa*, Lam.). These corals stand erect as they grew; and, after being traced for hundreds of yards, are again found at a corresponding height on the opposite side of the valley.

Fig. 111.



Caryophyllia cespitosa, Lam. (*Cladocora cespitosa*, Ehr.)

a. Stem with young stem growing from its side.
*a**. Young stem of same twice magnified.
b. Portion of branch, twice magnified, with the base of a lateral branch; the exterior ridges of the main branch appearing through the lamellæ of the lateral one.
c. Transverse section of same, proving, by the integrity of the

main branch, that the lateral one did not originate in a subdivision of the animal.

d. A branch, having at its base another laterally united to it, and two young corals at its upper part.

e. A main branch, with a full grown lateral one.

f. A perfect terminal star.

The corals are usually branched, but not by the division of the animal as some have supposed, but by the attachment of young individuals to the sides of the older ones, and we must understand this mode of increase, in order to appreciate the time which was required for the building up of the whole bed of coral during the growth of many successive generations.*

Among other fossil shells met with in these Sicilian strata, and which still continue to abound in the Mediterranean, I may mention *Turbo rugosus*, *Tornatella fasciata*, and other species figured in Pl. 1. (See Figs. 1. 3, 4, 5, 6, 7. 13, and 14.); but no shell is more conspicuous, from its size and frequent occurrence, than the great scallop, *Pecten Jacobæus* (see Fig. 112.), now so common in the neighbouring seas. We see this shell in the calcareous beds at Palermo in great numbers, in the limestone at Girgenti, and in that which alternates with volcanic rocks in the country between Syracuse and Vizzini, often at great heights above the sea.

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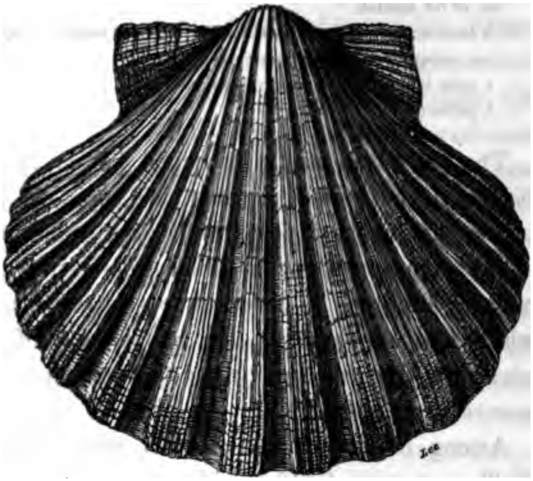
* I am indebted to Mr. Lonsdale for the details above given respecting the structure of this coral.

Fig. 112.



Pecten jacobæus; half natural size.

The more we reflect on the preponderating number of these recent shells, the more we are surprised at the great thickness, solidity, and elevation of the rocky masses in which they are entombed, and the vast amount of geographical change which has taken place since their origin. It must be remembered that, before they began to rise above the waters, the uppermost strata of the whole must have been thrown down. In order, therefore, to form a just conception of their antiquity, we must first examine singly the innumerable minute parts of which the whole is made up, the successive beds of shells, corals, volcanic ashes, conglomerates, and sheets of lava; and we must afterwards contemplate the time required for the gradual upheaval of the rocks, and the excavation of the valleys. As yet, the historical period seems scarcely to form an appreciable unit in the computation, for we find ancient Greek temples, like those of Girgenti (Agrigentum), built of the modern limestone of which we are speaking, and resting on a hill composed of the same; the site having remained to all appearance unaltered since the Greeks first colonized the island.

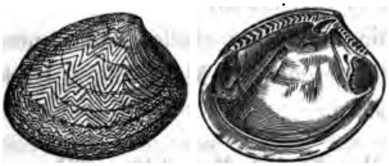
The modern geological date of the rocks in this region leads to another singular and unexpected conclusion, namely, that the fauna and flora of a large part of Sicily, are of higher antiquity than the country itself, having not only flourished before the lands were raised from the deep; but even before their materials were brought together beneath the waters. The chain of reasoning which conducts us to this opinion may be stated in a few words. The larger part of the island has been converted from sea into land since the Mediterranean was peopled with nearly all the living species of testacea and zoophytes. We may therefore presume that, before this region emerged, the same land and river shells, and almost all the same animals and plants, were in existence which now people Sicily; for the terrestrial fauna and flora of this island are precisely the same as that of other lands surrounding the Mediterranean.

There appear to be no peculiar or indigenous species, and those which are now established there must be supposed to have migrated from pre-existing lands, just as the plants and animals of the Neapolitan territory have colonized Monte Nuovo, since that volcanic cone was thrown up in the sixteenth century.

Such conclusions throw a new light on the adaptation of the attributes and migratory habits of animals and plants to the changes which are unceasingly in progress in the physical geography of the globe. It is clear that the duration of species is so great, that they are destined to outlive many important revolutions in the configuration of the earth's surface; and hence those innumerable contrivances for enabling the subjects of the animal and vegetable creation to extend their range; the inhabitants of the land being often carried across the ocean, and the aquatic tribes over great continental spaces. It is obviously expedient that the terrestrial and fluviatile species should not only be fitted for the rivers, valleys, plains, and mountains which exist at the era of their creation, but for others that are destined to be formed before the species shall become extinct; and, in like manner, the marine species are not only made for the deep and shallow regions of the ocean existing at the time when they are called into being, but for tracts that may be submerged or variously altered in depth during the time that is allotted for their continuance on the globe.

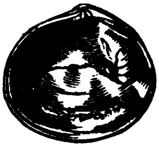
Older Pliocene strata — Norwich Crag. — We must now endeavour to carry our retrospect one step further, and treat of the era immediately antecedent to that last considered. Recent investigations have shown that the deposits provincially termed Crag in Norfolk and Suffolk, all of which were formerly confounded together, and referred to one period, may be subdivided into two very distinct groups. The oldest of these, comprising the Red and Coralline crag of Suffolk, will be described in the next chapter; the newest is that well seen in the neighbourhood of Norwich, as also at Southwold, in Suffolk. The shelly beds of sand and loam, sometimes forty feet thick, which there rest upon the chalk, were evidently accumulated where one or more rivers entered the sea. In this fluvio-marine formation, about twenty species of land and freshwater shells, and about ninety marine species, have been obtained. As in this number the proportion now known as living does not

Fig. 113.



Nucula Cobboldiæ.

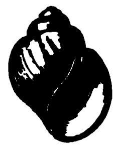
Fig. 114.



Tellina obliqua.

exceed the ratio of 60 per cent, the strata may be classed as Older Pliocene. Among the more common of the extinct testacea of these beds are *Nucula Cobboldiæ* (Fig. 113.) and *Tellina obliqua* (Fig. 114.) *Natica helicoides* (Fig. 115.) is an example of a species, formerly known only as fossil, but which has recently been found living in our seas.* The echinodermata and fish of this deposit have none of them been hitherto identified with living species; but this may in some degree be owing to the comparatively small progress made as yet in our knowledge of these departments of the British submarine fauna.

Fig. 115.



Natica helicoides, Johnston.

Bones of mammalia are frequently met with, and among them is the *Mastodon longirostris* (Fig. 121.), as determined by Mr. Owen from a specimen of the upper jaw found by J. B. Wigham, Esq. in 1838, at Postwick, near Norwich. In the same formation occur bones of the elephant, horse, pig, deer, and the jaws and teeth of field mice. (Fig. 132.) The femur of a seal, apparently distinct from any British species, has also been recognised by Mr. Owen.

Strata containing the same shells as those near Norwich have been found by Mr. Bean, at Bridlington, in Yorkshire.

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* See Phil. Mag. No. 104., May, 1840., p. 365.

Subapennine strata. — The Apennines, it is well known, are composed chiefly of secondary rocks, forming a chain which branches off from the Ligurian Alps and passes down the middle of the Italian peninsula. At the foot of these mountains, on the side both of the Adriatic and the Mediterranean, are found a series of tertiary strata, which form, for the most part, a line of low hills occupying the space between the older chain and the sea. Brocchi, as we have seen (p. 273.), was the first Italian geologist who described this newer group in detail, giving it the name of the Subapennines; and he classed all the tertiary strata of Italy, from Piedmont to Calabria, as parts of the same system. Certain mineral characters, he observed, were common to the whole; for the strata consist generally of light brown or blue marl, covered by yellow calcareous sand and gravel. There are also, he added, some species of fossil shells which are found in these deposits throughout the whole of Italy.

We have now, however, satisfactory evidence that the Subapennine beds of Brocchi belong, at least, to three periods. To the Miocene we can refer a portion of the strata of Piedmont, those of the hill of the Superga, for example, and those of freshwater origin in the Upper Val d'Arno; to the Older Pliocene part of the strata of northern Italy, of Tuscany, and of Rome; while the tufaceous formations of Naples, of Ischia, and the calcareous strata of Otranto, are referable to the Newer Pliocene, and in great part to the Post-Pliocene period.

That there is a considerable correspondence in the mineral composition of these different Italian groups is undeniable; but not that exact resemblance which should lead us to assume a precise identity of age, unless the fossil remains agreed very closely. It is now indispensable that a new scrutiny should be made in each particular district, of the fossils derived from the upper and lower beds, — especially such localities as Asti and Parma, where the formation attains a great thickness. From these places I possess about 200 species of shells, procured indiscriminately from the higher and inferior strata, and find the recent species to be in the proportion of at least one third. At Sienna the shells of the incumbent yellow sand are generally believed to approach much more nearly, as a whole, to the recent fauna of the Mediterranean than those in the subjacent blue marl.

The grayish brown or blue marl of the Subapennine formation is very aluminous, and usually contains much calcareous matter and scales of mica. Near Parma it attains a thickness of 2000 feet, and is charged throughout with marine shells, some of which lived in deep, others in shallow water, while a few belong to fresh water genera, and must have been washed in by rivers. Among these last I have seen the common *Limnea palustris* in the blue marl, filled with small marine shells. The wood and leaves, which occasionally form beds of lignite in the same deposit, may have been carried into the sea by similar causes. The shells, in general, are soft when first taken from the marl, but they become hard when dried. The superficial enamel is often well preserved, and many shells retain their pearly lustre, part of their external color, and even the ligament which unites the valves. No shells are more usually perfect than the microscopic foraminifera, which abound near Sienna, where more than a thousand full-grown individuals may be sometimes poured out of the interior of a single univalve of moderate dimensions.

The other member of the Subapennine group, the yellow sand and conglomerate, constitutes, in most places, a border formation near the junction of the tertiary and secondary rocks. In some cases, as near the town of Sienna, we see sand and calcareous gravel resting immediately on the Apennine limestone, without the intervention of any blue marl. Alternations are there seen of beds containing fluviatile shells, with others filled exclusively with marine species; and I observed oysters attached to many limestone pebbles. This appears to have been a point where a river, flowing from the Apennines, entered the sea when the tertiary strata were formed.

The sand passes in some districts into a calcareous sandstone, as at San Vignone. Its general superposition to the marl, even in parts of Italy and Sicily where the date of its origin is very distinct, may be explained if we consider that it may represent the deltas of rivers and torrents, which gained upon the bed of the sea where blue marl had previously been deposited. The latter, being composed of the finer and more transportable mud, would be conveyed to a distance, and first occupy the bottom, over which sand and pebbles would afterwards be spread, in proportion as rivers pushed their deltas further outwards. In some large tracts of yellow sand it is impossible to detect a single fossil, while in other places they occur in profusion. Occasionally the shells are silicified, as at San Vitale, near Parma, from whence I saw two individuals of recent species, one freshwater and the other marine (*Limnea palustris*, and *Cytherea concentrica*, Lam.), both perfectly converted into flint.*

Rome. — The seven hills of Rome are composed partly of marine tertiary strata, as those of Monte Mario, for example, of the Older Pliocene period, and partly of superimposed volcanic tuff, on the top of which are usually cappings of a fluviatile and lacustrine deposit. Thus, on Mount Aventine, the Vatican, and the Capitol, we find beds of calcareous tufa with incrusted reeds, and recent terrestrial shells, at the height of about 200 feet above the alluvial plain of the Tiber. The tusk of the mammoth has been procured from this formation, but the shells appear to be all of living species, and must have been imbedded when the summit of the Capitol was a marsh, and constituted one of the lowest hollows of the country as it then existed. It is not without interest that we thus discover the extremely recent date of a geological event which preceded an historical era so remote as the building of Rome.

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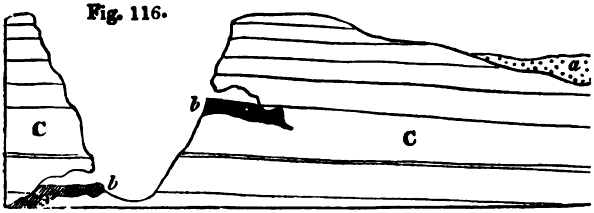
* For figures of some of the common Subapennine shells, see Pl. 1.

OSSEOUS BRECCIAS AND DEPOSITS IN CAVES OF THE PLIOCENE PERIOD.

Sicily.— Caverns filled with marine breccias, at the base of ancient sea cliffs, have been already mentioned in the sixth chapter; and it was noticed, respecting the cave of San Ciro, near Palermo, that above a bed of sand filled with sea-shells, almost all of recent species, was a breccia, composed of fragments of calcareous rock, and the bones of animals. (P. 152.) In the sand at the bottom of that cave, Dr. Philippi found about forty-five marine shells, all clearly identical with recent species, except two or three. The bones in the incumbent breccia are chiefly those of the mammoth (*E. primigenius*), with some belonging to an hippopotamus, distinct from the recent species, and smaller than that usually found fossil. (See Fig. 123.) Several species of deer, also, and, according to some accounts, the remains of a bear, were discovered. These mammalia are probably referable to the Post-Pliocene period.

That the tertiary limestone of the south of Sicily is sometimes full of caverns has been already mentioned; and the student will at once perceive, that all the quadrupeds of which the remains are found in the stalactite of these caverns, being of later origin than the rocks, must be re-

Fig. 116.



a. Alluvium. { containing the remains of quadrupeds
b, *b*. Deposits in caves, { for the most part extinct.

C. Limestone, containing the remains of shells of which above 80 per cent. are recent.

ferable to the close of the tertiary epoch, if not of still later date. The situation of one of these caves, in the valley of Sortino, is represented in the annexed section.

England.—In a cave at Kirkdale, about twenty-five miles N. N. E. of York, the remains of about 300 hyænas, belonging to individuals of every age, have been detected; and Dr. Buckland, after carefully examining the spot, has shown that the hyænas lived there; a fact attested by the quantity of their dung, which, as is the case of the living hyæna, is of nearly the same composition as bone, and almost as durable. In the cave were found the remains of the ox, young elephant, hippopotamus, rhinoceros, horse, bear, wolf, hare, water-rat, and several birds. All the bones have the appearance of having been broken and gnawed by the teeth of the hyænas; and they occur confusedly mixed in loam or mud, or dispersed through a crust of stalagmite which covers it. In these and many other cases it is supposed that portions of herbivorous quadrupeds have been dragged into caverns by beasts of prey, and have served as their food, an opinion quite consistent with the known habits of the living hyæna.

Other examples occur of fissures into which animals have fallen from time to time, or have been washed in from above, together with alluvial matter and fragments of rock detached by frost, forming a mass which may be united into a bony breccia by stalagmitic infiltrations. Frequently we discover a long suite of caverns connected by narrow and irregular galleries, which hold a tortuous course through the interior of mountains, and seem to have served as the subterranean channels of springs and engulphed rivers. Many streams in the Morea are now carrying bones, pebbles, and mud into underground passages of this kind.* If, at some future period, the form of this country should be wholly altered by subterranean movements and new valleys shaped out by denudation, many portions of the former channels of these engulphed streams may communicate with the surface, and become the dens of wild beasts, or the recesses to which quadrupeds retreat to die. Certain caves of France, Germany, and Belgium, may have passed successively through these different conditions, and in their last state may have remained open to the day for several tertiary periods. It is nevertheless remarkable, that in Europe the fossil remains of mammalia belong almost exclusively to those of the Pliocene or Post-Pliocene periods, and not to the Miocene or Eocene epochs, and when

* See Principles of Geology.

they are accompanied by land or river shells, these agree in great part, or entirely, with recent species.

As the preservation of the fossil bones is due to a slow and constant supply of stalactite, brought into the caverns by water dropping from the roof, the source and origin of this deposit has been a subject of curious inquiry. The following explanation of the phenomenon has been recently suggested by the eminent chemist Liebig. On the surface of Franconia, where the limestone abounds in caverns, is a fertile soil, in which vegetable matter is continually decaying. This mould or humus, being acted on by moisture and air, evolves carbonic acid which is dissolved by rain. The rain water, thus impregnated, permeates the porous limestone, dissolves a portion of it, and afterwards, when the excess of carbonic acid evaporates in the caverns, parts with the calcareous matter, and forms stalactite.

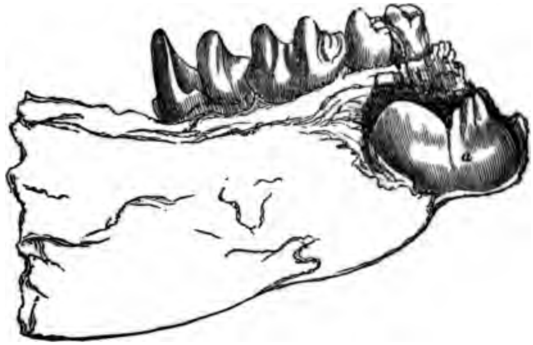
Australian cave-breccias. — Ossiferous breccias are not confined to Europe, but occur in all parts of the globe; and those lately discovered in fissures and caverns in Australia correspond closely in character with what has been called the bony breccia of the Mediterranean, in which the fragments of bone and rock are firmly bound together by a red ochreous cement.

Some of these caves have been examined by Sir. T. Mitchell, in the Wellington Valley, about 210 miles west of Sydney, on the river Bell, one of the principal sources of the Macquarie, and on the Macquarie itself. The caverns often branch off in different directions through the rock, widening and contracting their dimensions, and the roofs and floors are covered with stalactite. The bones are often broken, but do not seem to be water-worn. In some places they lie imbedded in loose earth, but they are usually included in a breccia.

The remains found most abundantly are those of the kangaroo, of which there are four species, besides which the genera *Hypsiprymnus*, *Phalangista*, *Phascolomys*, and *Dasyurus*, occur. There are also bones, formerly conjectured by some osteologists to belong to the hippopotamus, and by others to the dugong, but which are now referred by Mr. Owen to a marsupial genus, allied to the *Wombat*.

In the fossils above enumerated, several species are larger than the largest living ones of the same genera now known in Australia. The annexed figure of the right side of a lower jaw of a kangaroo (*Macropus atlas*, Owen) will at once be seen to exceed in magnitude the corresponding part of the largest living kan-

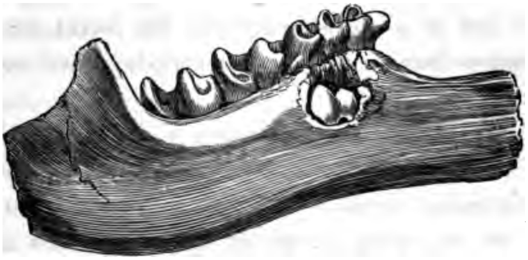
Fig. 117.



Macropus atlas, Owen.
a, permanent false molar, in the alveolus.

garoo, which is represented in Fig. 118. In both these specimens part of the substance of the jaw

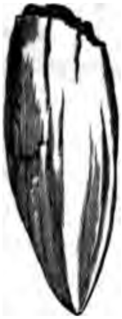
Fig. 118.



Lower jaw of largest living species of kangaroo.
(*Macropus major.*)

has been broken open, so as to show the permanent false molar (*a*, Fig. 117.) concealed in the socket. From the fact of this molar not having been cut, we learn that the individual was young, and had not shed its first teeth. In Fig. 119. a front tooth of the same species of Kangaroo is represented. The discovery of Mr. Owen, that all these extinct quadrupeds of Australia belong to the marsupial family, or, in other words, that they are referable to the same peculiar type of organization which now distinguishes the Australian mammalia from other parts of the globe, is full of interest, because we find, in like manner, that in those regions of South America to which the families of the Armadillo, Llama, and Capybara, are now confined, there are extinct species of the same families in a fossil state, facts which point to a general law of relationship between the recent mammiferous fauna and that of the periods immediately antecedent.

Fig. 119.

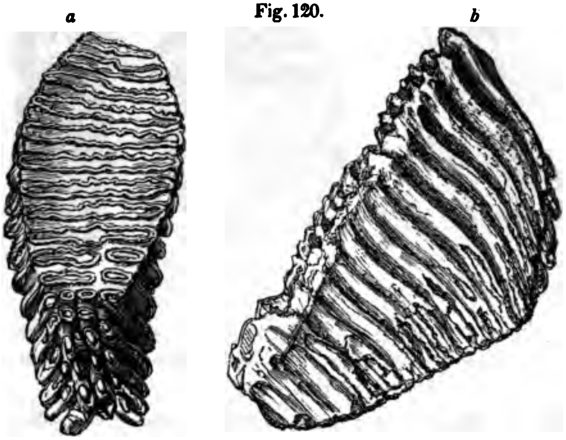


Incisor of *Macropus*.

Whether the breccias, above alluded to, of the Wellington Valley, appertain strictly to the Pliocene period cannot be affirmed with certainty, until we are more thoroughly acquainted with the recent quadrupeds of the same district, and until we learn what species of fossil land shells, if any, are buried in the deposits of the same caves.

To those who have never studied comparative anatomy it may seem scarcely credible, that a single bone taken from any part of the skeleton may enable a skilful osteologist to distinguish, in many cases the genus, and sometimes the species, of quadruped to which it belonged. Although few geologists can aspire to such knowledge, which must be the result of long practice and study, they will nevertheless derive great advantage from learning what is comparatively an easy task, to distinguish the principal divisions of the mammalia by the forms and characters of their teeth. The annexed figures, all taken from original specimens, may be useful in assisting the student to recognise the teeth of many genera most frequently found fossil in Europe: —

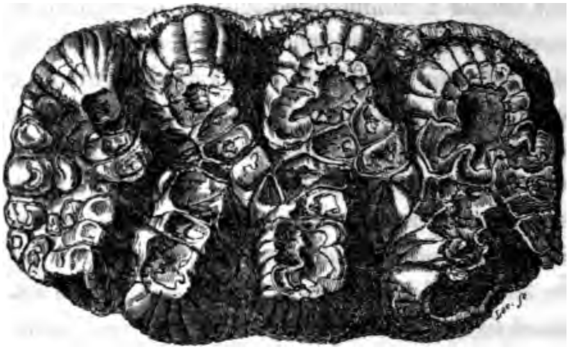
Fig. 120.



Elephas primigenius (or Mammoth); molar of upper jaw, right side; one-third of nat. size.

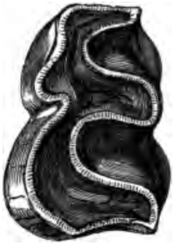
a. grinding surface. *b.* side view.

Fig. 121.



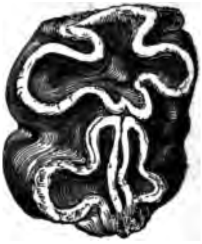
Mastodon longirostris (Norwich Crag., Postwick); second true molar, left side, upper jaw; grinding surface, nat. size. (See p. 300)

Fig. 122.



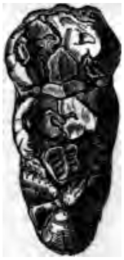
Rhinoceros.

Fig. 123.



Hippopotamus.

Fig. 124.



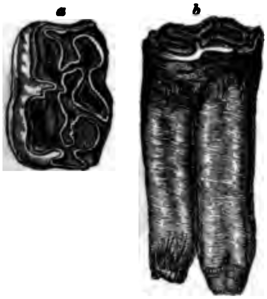
Pig.

Fig. 122. Rhinoceros; fossil from freshwater beds of Grays, Essex (see p. 287.); penultimate molar, lower jaw, left side; two thirds of nat. size.

Fig. 123. Hippopotamus; from cave near Palermo. (See p. 306.); molar tooth; two thirds of nat. size.

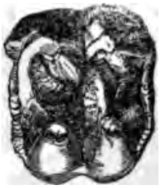
Fig. 124. *Sus scrofa*, Lin. (common pig); from shell marl, Forfarshire; posterior molar, lower jaw; nat. size.

Fig. 125.



Horse.

Fig. 126.

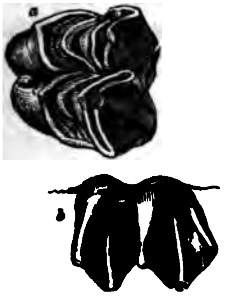


Tapir.

Fig. 125. *Equus caballus*, Lin. (common horse); from the shell-marl, Forfarshire; second molar, lower jaw.
a. grinding surface, two thirds nat. size.
b. side view of same, half nat. size.

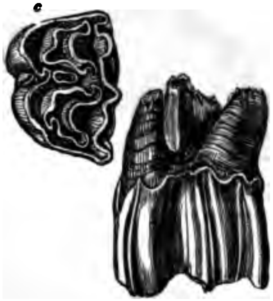
Fig. 126. *Tapirus Americanus*; recent; third molar, upper jaw; nat. size.

Fig. 127.



a. b. Deer.

Fig. 128.

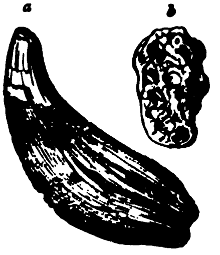


c. d. Ox.

Fig. 127. Elk (*Cervus alces*, Lin.); recent; molar of upper jaw.
a. grinding surface. *b.* side view; two thirds of nat. size.

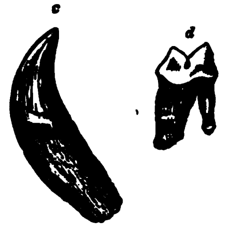
Fig. 128. Ox, common, from shell-marl, Forfarshire; true molar upper jaw; two thirds nat. size.
c. grinding surface. *d.* side view.

Fig. 129.



Bear.

Fig. 130.

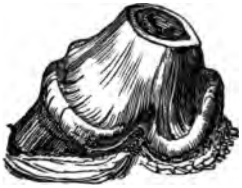


Tiger.

Fig. 129. *a.* incisor of bear (*Ursus spelæus*); from cave near Liege.
b. molar of left side, upper jaw; one third of nat. size.

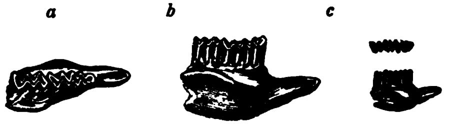
Fig. 130. *c.* incisor of tiger (*Felis tigris*); recent.
d. outside of posterior molar, lower jaw; one third of nat. size.

Fig. 131.



Hyæna; second molar, left side, lower jaw; nat. size. Cave of Kirkdale (see p. 307.)

Fig. 132.



Teeth of a new species of *Arvicola* (field-mouse); from the Norwich Crag. (See p. 300.)

a. grinding surface. *b.* side view of same.
c. nat. size of *a* and *b.*

CHAPTER XIV.

MIOCENE FORMATIONS.

Strata of Suffolk termed crag — Distinction of red and coralline crag — Fossils, and proportion of recent species — Inferences as to climate — Faluns of Touraine — Shells and corals — Comparison of the Faluns and the Suffolk crag — Whether contemporaneous — Miocene strata of Bordeaux, Switzerland, Lisbon, Styria, Mayence, and the Val d'Arno.

The Miocene formations, corresponding for the most part with those named "middle tertiary," will next claim our attention. Among the strata referred to this division in the 12th chapter, those of Touraine in France, and Suffolk in England, were particularly mentioned; for, although there is a considerable difference in the fossils of these two groups, there is strong ground for suspecting that they were nearly contemporaneous.

The tertiary strata of Suffolk, to which the povincial name of "crag" has been given, are confined chiefly to the eastern part of that country, and may be divided into two masses, the upper of which has been termed the Red, and the lower the Coralline Crag.* The upper deposit consists chiefly of quartzose sand, with occasional intermixture of shells, for the most part rolled, and sometimes comminuted. The lower or Coralline crag is of very limited extent, ranging over an area about twenty miles in length, and three or four in breadth, between the rivers Alde and Stour. It is generally calcareous and marly,—a mass of shells and small corals, passing occasionally into a soft building-stone. At Sudbourn, near Orford, where it assumes this character, are large quarries, in which the bottom of it has not been reached at the depth of fifty feet. At some places in the neighbourhood, the softer mass is divided by thin flags of hard limestone, and corals placed in the upright position in which they grew.

The Red crag is distinguished by the deep ferruginous or ochreous color of its sands and fossils, the coralline by its white color. Both formations are of moderate thickness; the red crag rarely exceeding forty, and the coralline seldom amounting to twenty, feet. But their importance is not to be estimated by the density of the mass of strata, or its geographical extent, but by the extraordinary richness of its organic remains, belonging to a very peculiar type, which seems to characterize the state of the living creation in the north of Europe during the last part of the Miocene era.

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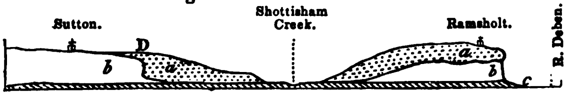
* See paper by E. Charlesworth, Esq.; London and Ed. Phil. Mag. No. xxxviii. p. 81., Aug. 1835.

For a large collection of the fish, echinodermata, shells, and corals of the deposits in Suffolk, we are indebted to the labors of Mr. Searles Wood. Of testacea alone he has obtained about 230 species from the Red, and 345 from the Coralline crag, about 150 being common to each. The proportion of recent species in the newer group has been found to be about 30 per cent., and that in the older or coralline, about 20. Whenever the two divisions are met with in the same district, the red crag lies uppermost; and, in some cases, as in the section represented in Fig. 133, it is observed that the older or coralline mass *b* had suffered denudation before the newer formation *a* was thrown down upon it. At D there is not only a distinct cliff, eight or ten feet high, of coralline crag, running in a direction N. E. and S. W., against which the red crag abuts with its horizontal layers; but

Fig. 133.



Section near Ipswich, in Suffolk.

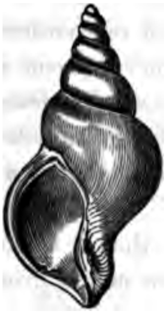
a. Red crag. *b.* Coralline crag. *c.* London clay.

this cliff occasionally overhangs. The rock composing it is drilled everywhere by *Pholades*, the holes which they perforated having been afterwards filled and covered over when the newer sandy beds were thrown down. Such a cliff may have been caused by submarine denudation, in a shallow sea; and, had the red crag been equally solid, it would probably have presented many similar perpendicular cliffs; for beds, ten or twelve feet thick, of loam or sand, in this formation, are often seen to be unconformable to older beds, which have been in part cut away. The layers of sand in this upper or Red crag often resemble those of a shifting sand bank; for they are inclined diagonally, and the planes of stratification are sometimes directed in the same quarry to the four cardinal points of the compass, as at Butley. That here, and in many other localities, this structure has not been due to any subsequent rearrangement of particles, is proved by each bed being made up of flat pieces of shell which lie parallel to the planes of the smaller strata.

Some fossils, which are very abundant in the Red crag, have never been found in the white or Coralline division; as, for example, the *Fusus contrarius* (Fig. 134.), and several species of *Buccinum* or *Nassa*, and *Murex*. (See Figs. 135, 136.), which two genera seem never to have been discovered in the lower crag.

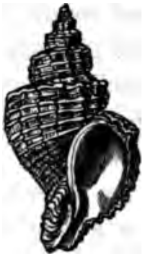
Fossils characteristic of the Red Crag.

Fig. 134.



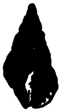
Fusus contrarius.

Fig. 135.



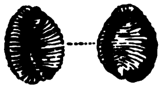
Murex alveolatus.

Fig. 136.



Nassa granulata.

Fig. 137.



Cypræa coccinelloides.

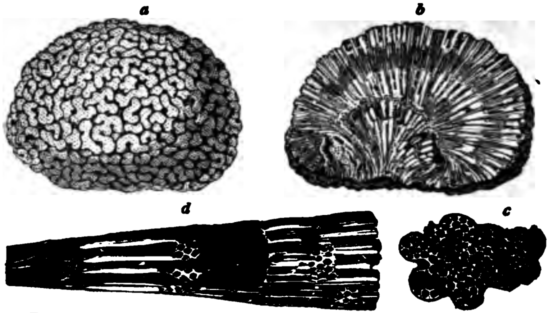
Fig. 134. half nat. size; the others nat. size.

Among the bones and teeth of fishes are those of large sharks (*Carcharias*), and a gigantic skate of the extinct genus *Myliobates*, and many other forms, some common to our seas, and many foreign to them.

The distinctness of the fossils of the Coralline crag arises, doubtless, in part from higher antiquity, but in some degree, also, from a difference in the geographical conditions of the submarine bottom. The prolific growth of corals, echini, and a prodigious variety of testacea, implies a region of deep and tranquil water; whereas, the red crag may have been formed afterwards on the same spot, when the water was shallower and more frequently turbid. In the mean time the climate may have become somewhat cooler, many of the stone-building zoophytes which flourished in the first period may have disappeared, and hence the fauna of the Red crag may have acquired a character more nearly resembling that of our northern seas, as is implied by the large development of certain sections of the genera *Fusus*, *Buccinum*, *Purpura*, and *Trochus*, proper to higher latitudes, and which are wholly wanting or feebly represented in the inferior crag.

The corals of the lower crag of Suffolk belong in great part to a genera unknown in the living creation, and are of a very peculiar structure; as for example, that represented in the annexed Fig. (138.), which is one of several species having a

Fig. 138.



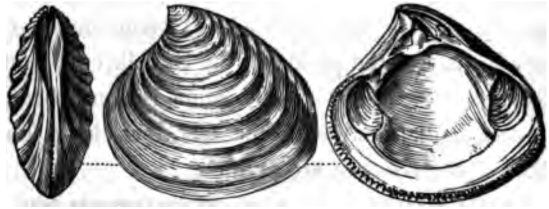
Fascicularia aurantium, Milne-Edwards. Family, *Tubuliporidæ*, of same author.

Coral of extinct genus, from the inferior or coralline crag, Suffolk.

a. exterior. *b.* vertical section of interior.
c. portion of exterior magnified.
d. portior of interior magnified, showing that it is made up of long, thin, straight tubes, united in conical bundles.

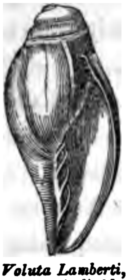
globular form. The great number and variety of these zoophytes probably indicate an equitable climate, free from intense cold in winter. On the other hand, that the heat was never excessive is confirmed by the prevalence of northern forms among the testacea, such as the *Glycimeris*, *Cyprina*, and *Astarte*. Of the genus last mentioned (see Fig. 139.) there are about fourteen species, many of them being rich in individuals; and there is an absence of genera peculiar to hot climates, such as *Conus*, *Oliva*, *Mitra*, *Fasciolaria*, *Crassatella*, and others. The cowries (*Cypræa*, Fig. 137.), also, are small, and belong to a section (*Trivia*) now inhabiting the colder regions. A large volute, called *Voluta Lamberti* (Fig. 140.), may seem an exception; but it differs in form from the volutes of the torrid zone, and may, like the living *Voluta Magel-*

Fig. 139.



Astarte (*Crassina*, Lam.); *species common to upper and lower crag.*

Fig. 140.



Voluta Lamberti, young individ.

lanica, have been fitted for an extra-tropical climate.

The occurrence, however, of a species of *Lingula* at Sutton, is worthy of remark, as these *Brachiopoda* seem now confined to more equatorial latitudes, and the same may be said still more decidedly of a species of *Pyrula*, allied to *P. reticulata*. Whether, therefore, we may incline to the belief that the mean annual temperature was higher or lower than now, we may at least infer that the climate and geographical conditions were very distinct at the period of the Suffolk crag from those now prevailing in the same region; a conclusion in harmony with the fact, that about four fifths of the testacea are extinct.

Out of sixteen species of echinodermata found in the lower crag by Mr. Wood, none agree with the recent, so far as our present knowledge extends. Some of the forms, as the *Echinus*, now exist in the neighbouring sea; some are, according to M. Agassiz, peculiar; and some now only known in warmer latitudes.

Strata containing fossil shells, like those of the Suffolk crag, above described, have been found near Antwerp; and lately (1840) I observed a small patch of them near Valognes in Normandy. There is another deposit, also containing similar fossils, at St. George Bohon, and other places a few leagues to the South of Carentan;

but they have never been traced further southwards.

Faluns of Touraine. — Near the towns of Dinan and Rennes, in Brittany, and again in the provinces bordering the Loire, a tertiary formation, containing another assemblage of fossils, is met with, to which the name of *Faluns* has been long given by the French agriculturists, who spread the shelly sand and marl over the land, in the same manner as the crag was formerly much used in Suffolk. Isolated masses of these faluns occur from near the mouth of the Loire, near Nantes, as far as a district south of Tours. They are also found at Pontlevoy, on the Cher, about 70 miles above the junction of that river with the Loire, and 30 miles S. E. of Tours. They consist principally of sand and marl, in which are shells and corals, some entire, some rolled, and others in minute fragments. In certain districts, as at Doué, in the department of Maine and Loire, 10 miles S. W. of Saumur, they form a soft building-stone, chiefly composed of an aggregate of broken shells, corals, and echinoderms, united by a calcareous cement; the whole mass being very like the coralline crag near Aldborough and Sudbourn in Suffolk. The scattered patches of faluns are of slight thickness, rarely exceeding fifty feet; and between the district called Sologne and the sea they repose on a great variety of older rocks;

being seen to rest successively upon gneiss, clay-slate, and various secondary formations, including the chalk ; and, lastly, upon the upper freshwater limestone of the Parisian tertiary series, which, as before mentioned (p. 274.), stretches continuously from the basin of the Seine to that of the Loire.

At some points, as at Louans, south of Tours, the shells are stained of a ferruginous color, not unlike that of the red crag of Suffolk. The species are, for the most part, marine, but a few of them belong to land and fluviatile genera. Among the former, *Helix turonensis* (Fig. 45. p. 65.) is the most abundant. Remains of terrestrial quadrupeds are here and there intermixed, belonging to the genera mastodon, rhinoceros, hippopotamus, deer, and others, and these are accompanied by cetacea, such as the lamantine, morse, sea-calf, and dolphin, all of extinct species.

Out of 290 species of shells, collected by myself, in 1840, at Pontlevoy, Louans, Bossée, and other villages, 20 miles south of Tours ; and at Savigné, about 15 miles northwest of that place; 72 are identical with recent species, which is in the proportion of 25 per cent. A large number of the 290 species are common to all the localities, those peculiar to each not being more numerous than we might expect to find in different bays of the same sea.

The total number of species from the faluns, in my possession, is 302, of which 45 only were found by Mr. Wood to be common to the Suffolk crag. The corals of the faluns are, in like manner, very dissimilar from those of the crag, if we regard them solely in reference to species; but their resemblance is considerable, if we direct our chief attention to their generic forms. The number of corals obtained by me at Doué, and other localities before adverted to, amounts to about 43, as determined by Mr. Lonsdale, of which seven agree specifically with those of the Suffolk crag. Only one has, as yet, been identified with living species. But it is difficult, if not impossible, to institute at present a satisfactory comparison between fossil and recent *Polyparia*, from the deficiency of our knowledge of the living species. Some of the genera occurring fossil in Touraine, as the *Astrea*, *Lunulites*, and *Dendrophyllia*, have not been found in European seas north of the Mediterranean; nevertheless, the *Polyparia* of the faluns do not indicate a climate much warmer than that which now prevails on the southern coasts of Europe.

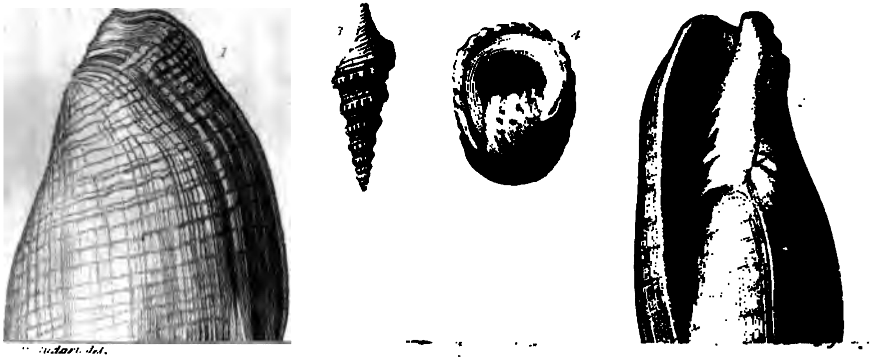
It was stated that, on comparing about 300 species of Touraine shells with about 450 from the Suffolk crag, 45 only were found to be common to both, which is in the proportion of only 15 per cent., an amount of agreement which is almost exactly the same as that found in the corals. Undoubtedly this amount is extremely small; although we must bear in mind that the numbers 300 or 450, above mentioned, represent fractions only of ancient faunas. It is like comparing a portion of the Mediterranean testacea with a part of those known in the British seas; and, for the sake of experiment, I requested Mr. G. Sowerby to examine 280 species of shells from the Mediterranean, and compare them with 600 of the best determined British species. Of these, 160 were found to be common to both collections, which is in the proportion of 57 per cent. This per-centage, however, is raised by the greater extent of our knowledge of the British testacea, than of the Suffolk Miocene shells, of which we are only acquainted with 450 species. Admitting, however, that the fossils of the Faluns and the Crag depart much more widely from each other than do the British shells from those of the Mediterranean, it is still conceivable that those tertiary formations may have been contemporaneous, if the Crag was deposited in a sea opening to the north, and the Faluns in another opening to the south, a barrier of land existing between the two. The breadth of such a barrier could not have been great, because Suffolk and Touraine are not 300 miles distant from each other, and some patches of the Crag extend south into Normandy, and others of the Faluns as far north as Rennes, in Brittany. But the isthmuses of Suez and Panama are also very inconsiderable, both in height and breadth, and yet the seas which they separate are inhabited by distinct testacea.

Other causes, however, may have coöperated powerfully with a geographical barrier to create a difference in the zoological productions of the neighbouring seas, of the faluns, and crag. Thus, for example, in the southern hemisphere at present, the transition is very sudden from a latitude enjoying a mild and equable climate, in which many tropical forms of testacea exist, to another where there is extreme cold, and where we may look for a fauna of an arctic character. Such a condition of things might have been almost as effectual as a strip of land, in preventing a free range of northern species towards the south, or of southern species towards the north.

In confirmation of this view, it should be remembered, that the assemblage of genera in the crag is somewhat anomalous, if compared with the present fauna of our temperate latitudes, containing, as we have seen, a mixture of northern and southern forms, such as we now observe in parts of the southern Atlantic. To a certain extent the same observation holds true in respect to the faluns of Touraine, where most of the shells do not depart from the Mediterranean type, although a few would seem to imply a tropical climate. Among these may be mentioned some large species of the genera *Conus*, *Terebra*, *Pyrula*, *Fasciolaria*, *Cerithium*, and *Cardita*.

M. Desnoyers, in 1825, expressed an opinion that the faluns were of the same age as the English crag, to which he was led by a similarity of mineral composition, and the general analogy of the fossil shells and zoophytes, together with the perfect identity of certain species. I dissented at the time from this conclusion, seeing that the species of shells were in general so distinct; but I am now inclined to come round to the same views, since I have ascertained that both formations contain a similar proportion of shells (about one fourth), identical with those now living. In this, however, and in almost every instance, the word *contemporaneous* must be understood in a large and liberal sense in geology; and when we refer both the Faluns and the Crag to some part of the Miocene period, we may still conceive that there were shades of difference in their relative ages, like that already pointed out in the Red and Coralline divisions of the Suffolk crag.

Bordeaux. — A great extent of country between the Pyrenees and the Gironde is overspread by tertiary deposits, which have been more particularly studied in the environs of Bordeaux



udart. del.

1. Voluta rarispina, Lam.k — 2. Mitra Dufresnei, Bast. — 3. Pleurotoma denticula Bast
4. Nerita Plutonis, Brong. — 5. Turritella Proto. Bast. — 6. Fasciolaria turbinelloides, Desh
7. Pleurotoma tuberculosa, Bast. — 8 a.b. Cardita Ajar, Brug.

Published by John Murray 1833

and Dax, from whence about 700 species of shells have been obtained. A large proportion of these shells belong to the same zoological type as those of Touraine; but many are peculiar, and the whole may probably constitute an older division of the Miocene period than the faluns of the Loire. We must wait, however, for further investigations, in order to decide this question with accuracy. The fossils figured in plate 3. are characteristic of the strata of Bordeaux and Dax.

Piedmont.—Many of the shells peculiar to the hill of the Superga, near Turin, agree with those found at Bordeaux and Dax; but the proportion of recent species is much less. The strata of the Superga consist of a bright green sand and marl, and a conglomorate with pebbles, chiefly of green serpentine, and are inclined at an angle of more than 70°. This formation, which attains a great thickness in the valley of the Bormida, is probably one of the oldest Miocene groups hitherto discovered.

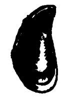
Molasse of Switzerland.—If we cross the Alps, and pass from Piedmont to Savoy, we find there, at the northern base of the great chain, and throughout the lower country of Switzerland, a soft green sandstone much resembling some of the beds of the basin of the Bormida, above described, and associated in a similar manner with marls and conglomerate. This formation is called in Switzerland "molasse," said to be derived from "mol," "*soft*," because the stone is easily cut in the quarry. It is of vast thickness, and probably divisible into several formations. Whether all these may belong to the Miocene period cannot yet be determined, as fossil shells are often entirely wanting; but such as have been met with in a few places appear to bear out this conclusion, which is strongly corroborated by the agreement of the fossil fishes of the molasse and faluns. Among those common to both, M. Agassiz pointed out to me *Lamna contortidens*, *Myliobates Studeri*, *Spherodus cinctus*, *Notidanus primigenius*, and others. Some species of mammalia are also common to the molasse and faluns.

Lisbon. — Marine tertiary strata near Lisbon contain shells which agree very closely with those of Bordeaux, and are therefore referred to the Miocene era. Thus, out of 112 species collected by Mr. Smith, between 60 and 70 were found to be common to the strata of Bordeaux and Dax, the recent species being in the proportion of 21 per cent.

Styria. — Another important series of formations, found at the eastern extremity of the Alps in Styria, and which spread thence into the plains of Hungary, have also been referred to the same age. Nearest to the foot of the Alps appears the lowest of three natural groups, into which they have been classed: it consists of sandstones, conglomerates, and marls, which are intersected by the rivers Mur, Raab, and Drave. The second group is characterized at Wildon by a coralline limestone not less than 400 ft. thick. In the third group, which occurs at a still greater distance from the mountains, beds of limestone are met with, which exhibit a perfectly oolitic structure. In the middle group, both in Styria and the basin of Vienna, the shells are considered to agree, on the whole, with the species of the Loire, Gironde, and other Miocene basins. How far the lowest and uppermost systems depart chronologically from the same type remains for future investigation.

Mayence.—The tertiary strata near Mayence contain in abundance the *Mytilus Brardii* (Fig. 141.), and several other characteristic Miocene fossils. They occupy a tract from five to twelve miles in breadth, extending along the left bank of the Rhine from Mayence to the neighbourhood of Manheim, and are again found to the east, north, and southwest of Frankfort. In some places they have the appearance of a freshwater formation; but in others, as at Alzey, the shells are for the most part marine. *Cerithia* are in great profusion, which indicates that the sea where the deposit was formed was fed by rivers; and the great quantity of fossil land shells, chiefly of the

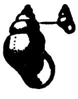
Fig. 141.



Mytilus Brardii.

genus *Helix*, confirm the same opinion. The variety in the species of shells is small, scarcely eighty having yet been discovered, according to Professor Bronn, of Heidelberg, while the individuals are exceedingly numerous; a fact which accords perfectly with the idea that the formation may have originated in a gulf or sea which, like the Baltic, was brackish in some parts, and almost fresh in others. A species of *Paludina* (Fig. 142.), very nearly resembling the recent *Littorina ulva*, is found throughout this basin. These shells are like grains of rice in size, and are often in such quantity as to form entire beds of marl and limestone. They are as thick as grains of sand, in stratified masses from 15 to 30 ft. in thickness.

Fig. 142.



Paludina.
Mayence.

It is most probable that the sandy beds of Eppelsheim are of the same age. In these the bones of several mammalia, and, among others, *Mastodon arvernensis*, and the new genus *Dinotherium*, have been met with. To the Miocene period we may also refer several detached lacustrine formations of Bavaria and Wurtemburg, and, among others, the freshwater beds of Georges Gemund, where, as in Touraine, we find an association of the genera Palæotherium, Mastodon, and Rhinoceros; the deposits of Osnabruck and other parts of Westphalia, and others, of wide extent, in Volhynia and Podolia, appear, also, to agree, by their fossils, with the Miocene strata of Bordeaux and Touraine.

Upper Val d'Arno.—There are a great number of isolated tertiary formations, of freshwater origin, resting on primary and secondary rocks in different parts of Europe, in the same manner as we now find small lakes scattered over our continents and islands, wherein deposits are forming, quite detached from all contemporary marine strata. To determine the age of such groups, with reference to the great chronological series established for the marine formations, must often be a matter of difficulty; since we have not always an opportunity of ascertaining what freshwater shells may have been contemporary with certain sets of marine species.

The deposit of the Upper Val d'Arno, near Florence, in Tuscany, presents an example of one of these detached lacustrine groups, in which shells of the genera *Anodon*, *Paludina*, and *Neritina*, of species not known as recent, have been found associated with teeth and skeletons of extinct species of bear, weasel, wolf, fox, hyæna, beaver, elephant, mastodon, tapir, horse, pig, rhinoceros, hippopotamus, deer, ox, buffalo, and other quadrupeds. Some of the above mammalia agree specifically with fossils known elsewhere to belong to the Miocene period.

CHAPTER XV.

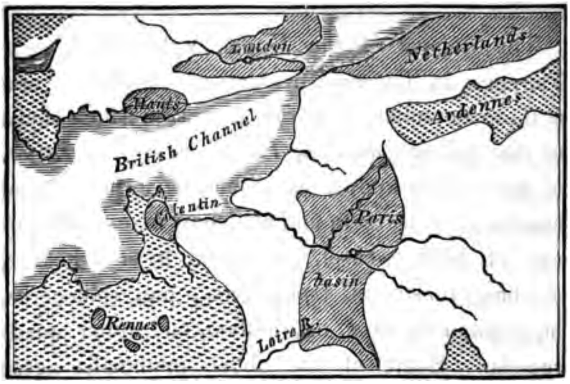
EOCENE FORMATIONS.

Position of London clay — Its fossils — Freshwater strata of Hants — Fossil mammalia — Strata of Kyson in Suffolk — Fossil monkey — Successive marine and freshwater formations in the Paris basin — Calcaire grossier — Calcaire siliceux — Gypsum — Fossil quadrupeds — Upper marine sand — Fossil shells.

English Eocene formations. — The accompanying map will explain to the student the position of

MAP OF THE PRINCIPAL TERTIARY BASINS OF THE EOCENE PERIOD.

Fig. 143.



▒ Primary rocks and strata older than the carboniferous series.

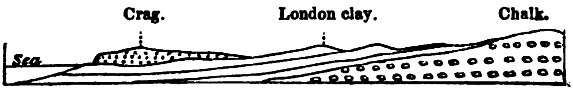
▨ Eocene formations.

N. B. — The space left blank is occupied by secondary formations from the old red sandstone to the chalk inclusive.

the principal Eocene formations of England, the Netherlands, and France. Those of England, it will be seen, are confined to two districts, usually called the basins of London and Hampshire. (See also Map, Plate 6.) These tracts are bounded by rising grounds, composed of chalk, except where the sea intervenes. That the chalk passes beneath the tertiary strata, as represented in Fig. 163. p. 387., we can not only infer from geological data, but can prove by numerous artificial sections at points where railways have been cut, wells sunk, or borings made, through the overlying beds.

In the section already given of the tertiary strata of Suffolk (p. 319.), it will be seen that the crag *a b* rests on a formation called the London clay (*c*), which there consists of alternating beds of blue and brown clay, with many nodules of calcareous stone, used for Roman cement. This formation is well seen in the neighbouring cliffs of Harwich, where the nodules contain many marine shells, and sometimes the bones of turtles. The relative position of the chalk, London clay, and crag, between the coast of Essex and the interior, may be understood by reference to the annexed diagram.

Fig. 144.



The Eocene strata of the London basin are very simple in their composition, consisting almost entirely of clay, sand, and shingle, from 200 to 600 feet in thickness. They have generally been divided into three groups, though by a very arbitrary classification; the uppermost of which has been called the Bagshot sand, the second the London clay, and the lowest the plastic clay and sand. In the first of these, composed of siliceous sand and sandstone, and some beds of marl, fossils are very rare; but the teeth of *Pristis*, or saw-fish, sharks, rays, and other species, brought to light in a railway cutting made in 1838, near Guildford, prove these sands to agree closely in age with the London clay, of the Isle of Sheppey, in which the same species are found.*

The blueish or dark argillaceous mass, called London clay, sometimes attains a thickness of 700 feet, as at High Beech, in Essex. Its stratification is often obscure. It frequently contains ovate nodules, or concretions of limestone, usually from a foot to 18 inches in diameter, which are traversed in various directions by cracks, dividing the whole into *septa*, or inclosures, whence the name septaria. These are sometimes continued through a thickness of 200 feet; and in some of them testacea, fruits, and the entire shells of turtles have been met with.

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* Buckland, Proceedings of Geological Society, No. 58. p. 687.

The plastic clay and sand ought never to have been classed as a distinct formation, but merely as the inferior portion of the London clay; since, in one of the earliest publications on this subject, Mr. Webster pointed out, in the Isle of Wight, a distinct alternation of the sands of the lower part of the series with clay 200 feet thick, containing septaria, and replete with the usual fossils of the neighbourhood of London.* The plastic clay sometimes attains a thickness of from 400 to 500 feet. It is made up of an indefinite number of beds of sand, shingle, clay, and loam, irregularly alternating. Some of the clay being used in potteries, the name of plastic clay has been given to the whole formation. The beds of shingle are composed of perfectly rolled chalk-flints, with here and there small pebbles of quartz. Heaps of these materials appear sometimes to have remained for a long time covered by a tranquil sea. Dr. Buckland states that he observed a large pebble in part of this formation at Bromley, to which five full-grown oyster-shells were affixed, in such a manner as to show that they had commenced their first growth upon it, and remained attached through life.*

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* See also Professor Sedgwick and Mr. Bowerbank in confirmation of this opinion, Phil. Mag. and Geol. Proceedings.

The fossils of these Eocene strata differ almost entirely from those of the crag. Out of 400 species of shells, scarcely any can be identified with those now living. Upon the whole, they resemble the testaceous fauna of the tropics; a conclusion favored by the occurrence of many species of *Conus*, *Mitra* and *Voluta*, a large *Cypræa*, a very large *Rostellaria*, and shells of the genera *Terebellum*, *Cancellaria*, *Crassatella*, and others, with four or more species of *Nautilus*. (See Figures, p. 341.) There are fish, also, which indicate a warm climate; among which may be mentioned a sword-fish (*Tetrapterus priscus*, Agassiz), about eight feet long, and a saw-fish (*Pristis bisulcatus*, Ag.), about ten feet in length; genera foreign to the British seas.

These fossils have been found in the island of Sheppey, which is composed of London clay, where also, as I learn from M. Agassiz, the remains of no less than fifty other species of fish have been discovered.

An immense number of fruits and seeds of plants, penetrated with iron pyrites, have been procured from the clay of Sheppey, belonging, it is supposed, to more than 700 distinct species.

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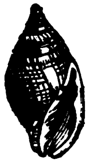
* Geological Transactions, 1st Series, Vol. iv. p. 300.

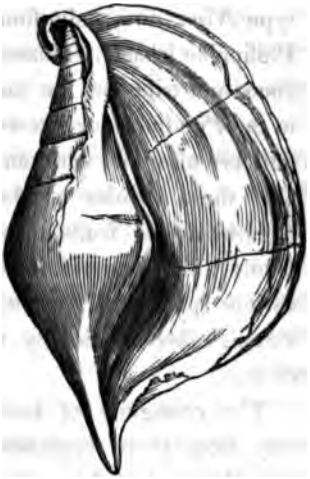
FOSSIL SHELLS OF THE LONDON CLAY.

Fig. 145.



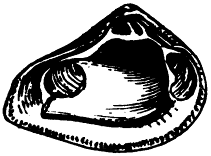
Mitra scabra.

Fig. 146.



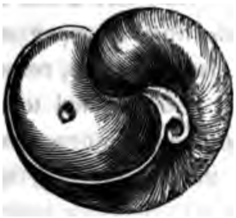
Rostellaria macroptera, Sow.
one third of nat. size.

Fig. 147.



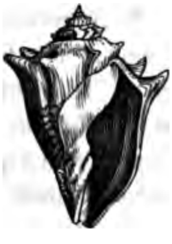
Crassatella sulcata.

Fig. 148.



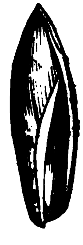
Nautilus centralis.

Fig. 149.



Voluta athleta.

Fig. 150.



Terebellum fusiforme.

Mr. Bowerbank, in a valuable publication devoted to the description of these fossils, has shown that many of them are decidedly referable to families of plants now confined to tropical regions. He has described thirteen fruits of palm of the recent type *Nipa*, now only found in the Molucca and Philippine islands. These plants are allied to the cocoa-nut tribe on the one side, and on the other to the *Pandanus*, or screw-pine. Species of cocoa-nuts are also met with, and other kinds of palms; also three species of *Anona*, or custard-apple; cucurbitaceous fruits, also (the gourd and melon family), are in considerable abundance. Fruits of various species of *Acacia*, are in profusion; and, although less decidedly tropical, imply a warm climate.

The contiguity of land may be inferred not only from these vegetable productions, but also from the teeth and bones of crocodiles and turtles, since these creatures, as Mr. Conybeare has remarked, must have resorted to some shore to lay their eggs. Very recently (1839) Mr. Owen has recognised among the fossils from Sheppey and Herne Bay the bones of a large serpent, resembling a *Boa* or *Python*, and a bird allied to the vultures, together with a quadruped of a new genus (*Hyracotherium*), allied to the hyrax, hog, and chæropotamus.

Freshwater strata of the Hampshire basin.—In the northern part of the Isle of Wight, and part of the opposite coast of Hampshire, freshwater strata occur resting on the London clay. They are composed chiefly of calcareous and argillaceous marls, with a few layers of limestone, sometimes slightly siliceous. The marls are often green, and bear a considerable resemblance to certain green marls of Auvergne and the neighbourhood of Paris, which will afterwards be mentioned.

At Headon Hill, on the north side of Alum Bay, in the Isle of Wight, is a vertical precipice, where the horizontal freshwater strata are exposed for a thickness of 400 feet. About half way up in the cliff appear beds in which there is a mixture of marine and freshwater shells; implying a temporary return of the sea, before and after which the waters of a lake or some large river prevailed over the same area. In these formations *Gyrogonites*, or the fossil seed-vessels of *Chara* (see p. 67.), are frequent, and shells of the genera *Limnea*, *Planorbis*, *Melanopsis*, and *Paludina*. At Binstead, near Ryde, several quadrupeds, corresponding in genera, and, for the most part, in species, with the celebrated fossils of the gypsum near Paris, have been detected in the freshwater limestone. They belong to the genera *Palæotherium* (four species), *Anoplotherium* (two species), *Chæropotamus*, and *Dichobunes;* which last, when the remains were first found at Binstead, was supposed to be a musk deer.*

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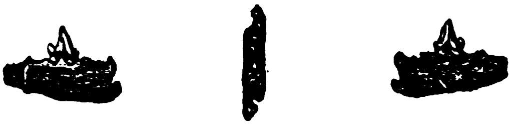
* See Owen on the fossils found by Mr. Pratt and Rev. W. D. Fox, Geol. Proceed., No. 59, p. 1.

Strata of Kyson in Suffolk. — At Kyson, a few miles east of Woodbridge, is a bed of clay, twelve feet thick, beneath which is a deposit of yellow and white sand, the age of which is matter of considerable interest, in consequence of many peculiar fossils contained in it. The incumbent clay, which is devoid of fossils, can be shown, by position, to underlie the red crag of Suffolk, and is probably a member of the Eocene formation. In this sand has been found the first example of a fossil quadrumanous animal discovered in Great Britain, namely, the teeth and part of a jaw, shown by Mr. Owen to belong to a monkey of the genus *Macacus* (see fig. 151.). The mammiferous fossils, first met with in the same bed, where those of an opossum (*Didelphys*) and an insectivorous bat (see figs. 152. and 153.), together with many teeth of fishes of the shark family, some of new and peculiar species, but two of them, according to M. Agassiz, agreeing with those found in the red

Fig. 151.

Molar of monkey (Maccaus).

Fig. 152.



Molar and part of jaw of opossum.

crag, namely, *Lamna contortidens* and an *Otodus*. More recently (1840) Mr. Colchester has obtained other mammalian relics from Kyson, among which Mr. Owen has recognised several teeth of the genus *Hyracotherium*, and the vertebræ of a large serpent, probably a *Boa*. As the remains both of the *Hyracotherium* and *Boa* have also been met with in the London clay, as before remarked, these fossils confirm the opinion previously entertained, that the Kyson sand belongs to the Eocene period. The *Macacus*, therefore, constitutes the first example of any quadrumanous animal found in strata as old as the Eocene, or in a latitude so far from the equator (52° N.). It was not until after the year 1836 that the existence of any fossil quadrumana were brought to light. Since that period they have been found in France, India, and Brazil. Those in France were procured at Sansan, near Auch, in the department of Gers, about forty miles west of Toulouse, in lat. 43° 40′ N., in freshwater strata, probably of the Miocene period. They were associated with the bones of the Dinotherium, Mastodon, Rhinoceros, and other mammifers.

Fig. 153.

Molars of insectivorous bats, twice nat. size.

Paris basin. — No formations can be more dissimilar in mineral character than the Eocene deposits of England and Paris; those of our own island being almost exclusively of mechanical origin, — accumulations of mud, sand, and pebbles; while in the neighbourhood of Paris we find strata inclosing a similar assemblage of organic remains, but composed partly of a coarse white limestone, and partly of a compact siliceous limestone of great thickness, with here and there intercalated beds of crystalline gypsum, or pure flint.

The area which has been called the Paris basin is about 180 miles in its greatest length from northeast to southwest, and about 90 miles from east to west. The space may be described as a depression in the chalk, which has been filled up by alternating groups of marine and freshwater strata. MM. Cuvier and Brongniart attempted, in 1811, to distinguish five different formations, comprising three freshwater and two marine, which alternated with each other. It was imagined that the waters of the ocean had been by turns admitted and excluded from the same region; but the subsequent investigations of several geologists, especially of M. Constant Prevost,* have led to great modifications in these theoretical views; and now that the true order of succession is better understood, it appears that several of the deposits, which were supposed to have originated one after the other, were, in fact, in progress at the same time by the joint action of the sea and rivers.

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* Bulletin des Sci. de la Soc. Philom. May, 1825., p. 74.

The order of superposition may be thus briefly expressed, beginning with the lowest beds: —

1st. Three formations of contemporaneous date, resting on the fundamental chalk, and, in some places, alternating with each other; namely, 1. freshwater beds, containing plastic clay and lignite: 2. marine limestone (calcaire grossier); 3. freshwater limestone (calcaire siliceux).

2dly. Marls and gypsum, with bones of quadrupeds, in part contemporaneous with the preceding, and in part posterior.

3dly. Upper marine sands.

4thly. Upper freshwater marls, with siliceous millstone.

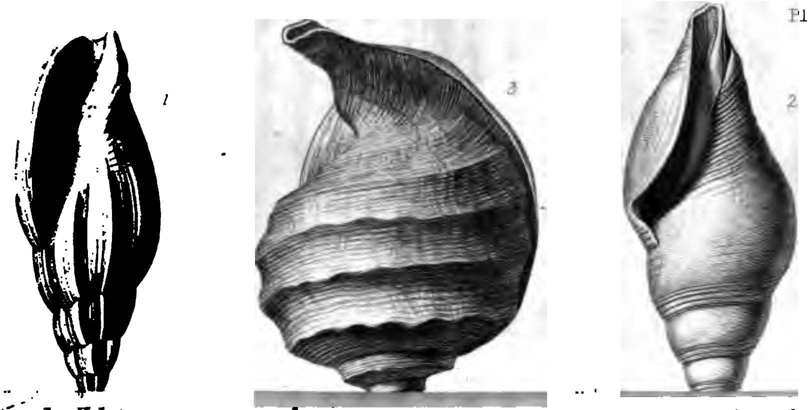
Immediately upon the chalk there is usually a layer of broken chalk-flints, often cemented into a breccia by siliceous sand. These flints probably indicate the action of the sea upon reefs of chalk when a portion of that rock had emerged, and before the regular tertiary beds were superimposed.

Upon this flinty stratum, or, if it be wanting, upon the chalk itself, rests frequently a deposit of clay and lignite, which includes the remains of freshwater shells and driftwood, and was, at first, regarded as a proof that the Paris basin had originally been filled with freshwater. But it has since been shown that strata of this character are of very partial extent, and have been repeated again and again in different parts of the overlying series. The phenomena, in fact, lead us simply to infer, that a river charged with argillaceous sediment entered a bay of the sea, and drifted into it, from time to time, freshwater shells and wood.

Calcaire grossier. — The formation called calcaire grossier consists of a coarse limestone, often passing into sand. It contains by far the greater number of the fossil shells which characterize the Paris basin. (See Pl. 4.) No less than 400 distinct species have been procured from a single spot near Grignon. They are imbedded in a calcareous sand, chiefly formed of comminuted shells, in which, nevertheless, individuals in a perfect state of preservation, both of marine, terrestrial, and freshwater species, are mingled together. Some of the marine shells may have lived on the spot; but the *Cyclostoma* and *Limnea* must have been brought thither by rivers and currents, and the quantity of triturated shells implies considerable movement in the waters.

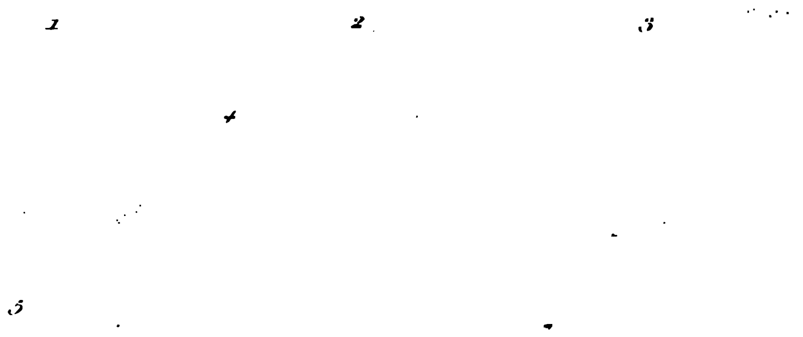
Nothing is more striking in this assemblage of fossil testacea than the great proportion of species referable to the genus *Cerithium.* (See fig. 154.) There occur no less than 137 species of this genus

Plate 4.



1. *Voluta costaria.* Lamk. _2. *Pleurotoma clavicularis*. _3. *Cassidaria carinata*. Lamk.
4. *Nerita tricarinata.* Lamk. _ 5. *Calyptræa trochiformis.* Lamk. _ 6 *Turritella imbricataria.* Lamk. _ 7. *Voluta digitalina.* Lamk. _8. *Natica epiglottina* Lamk.
9 *Solarium canaliculatum.* Lamk. _10 *Cardita planicosta.* Desh.

London Published by John Murray 1833

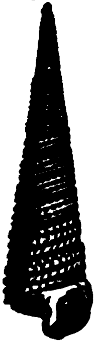


1. 2. 3. 4. Triloculina inflata. Desh. 5. 6. 7. 8. Quinqueloculina striata. Desh.
9. 10. 11. Calcarina rarispina. Desh. 12. 13. 14. Clavulina corrugata. Desh.
15. 16. 17. 18. Spirolina stenostoma. Desh.

London, Published by John Murray. Decr. 1831.

the Paris basin, and almost all of them in ıe calcaire grossier. Now the living *Cerithia*

Fig. 154.



*Cerithium cinctum.**

inhabit the sea near the mouths of rivers, where the waters are brackish; so that their abundance in the marine strata now under consideration is in harmony with the hypothesis, that the Paris basin formed a gulf into which several rivers flowed, the sediment of some of which gave rise to the beds of clay and lignite before mentioned; while a distinct freshwater limestone, called calcaire siliceux, which will presently be described, was precipitated from the waters of others situated further to the south.

In some parts of the calcaire grossier round Paris, certain beds occur of a stone used in building, and called by the French geologists "Miliolite limestone." It is almost entirely made up of millions of microscopic shells, of the size of minute grains of sand, which all belong to the class Foraminifera. Figures of some of these are given in the annexed plate (Pl. 5.). As this miliolitic stone never occurs in the Faluns, or Miocene strata of Brittany and Touraine, it often furnishes the geologist with a useful criterion for distinguishing the detached Eocene and Miocene formations, scattered over those and other adjoining provinces.

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* This species is found both in the Paris and London basins.

Calcaire siliceux. — This compact siliceous limestone extends over a wide area. It resembles a precipitate from the waters of mineral springs, and is often traversed by small empty sinuous cavities. It is, for the most part, devoid of organic remains, but in some places contains freshwater and land species, and never any marine fossils. The siliceous limestone and the calcaire grossier occupy distinct parts of the Paris basin, the one attaining its fullest development in those places where the other is of slight thickness. They also alternate with each other towards the centre of the basin, as at Sergy and Osny; and there are even points where the two rocks are so blended together that portions of each may be seen in hand specimens. Thus, in the same bed, at Triel, we have the compact freshwater limestone, characterized by its *Limneæ*, mingled with the coarse marine limestone, through which the small multilocular shell, called milliolite, is dispersed in countless numbers. These microscopic testacea are also accompanied by *Cerithia* and other shells of the calcaire grossier. It is very extraordinary that in this instance both kinds of sediment must have been thrown down together on the same spot, and each has still retained its own peculiar organic remains.

From these facts we may conclude, that while to the north, where the bay was probably open to the sea, a marine limestone was formed, another deposit of freshwater origin was introduced to the southward, or at the head of the bay; for it appears that during the Eocene period, as now, the ocean was to the north, and the continent, where the great lakes existed, to the south. From that southern region we may suppose a body of fresh water to have descended, charged with carbonate of lime and silica, the water being perhaps in sufficient volume to freshen the upper end of the bay.

Gypsum and marls. — The next group to be considered consists of white and green marls, with gypsum. These were once supposed to be entirely subsequent in origin to the two groups already considered; but M. Prevost has pointed out that in some localities they alternate repeatedly with the calcaire siliceux, and in others with some of the upper members of the calcaire grossier. The gypsum, with its associated marl and limestone, is in greatest force towards the centre of the basin, where the two groups before mentioned are less fully developed: and M. Prevost infers, that while those two principal deposits were gradually in progress, the one towards the north, and the other towards the south, a river descending from the east may have brought down the gypseous and marly sediment.

It must be admitted, as highly probable, that a bay or narrow sea, 180 miles in length, would receive, at more points than one, the waters of the adjoining continent. At the same time, we must be prepared to find that the simultaneous deposition of two or more sets of strata in one basin, some freshwater and others marine, must have produced very complex results. But, in proportion as it is more difficult in these cases to discover any fixed order of superposition in the associated mineral masses, so also is it more easy to explain the manner of their origin, and to reconcile their relations to the agency of known causes. Instead of the successive irruptions and retreats of the sea, and changes in the chemical nature of the fluid, and other speculations of the earlier geologists, we are now simply called upon to imagine a gulf, into one extremity of which the sea entered, and at the other a large river, while other streams may have flowed in at different points, whereby an indefinite number of alternations of marine and freshwater beds would be occasioned.

The gypsum occurs in the form of a saccharoid rock, in the hill of Montmartre at Paris, and other central parts of the basin. Although the lower beds of it alternate with the marine calcaire grossier, it must be considered on the whole as a freshwater formation, as it contains land and fluviatile shells, together with fragments of palm wood, and great numbers of skeletons of quadrupeds and birds; an assemblage of organic remains, on which the anatomical labors of Cuvier have conferred great celebrity. The bones of freshwater fish, also, and of crocodiles, and many other reptiles, both land and fluviatile, occur in this rock. The skeletons of mammalia are usually isolated, often entire, the most delicate extremities being preserved; as if the carcasses, clothed with their flesh and skin, had been floated down soon after death, and while they were still swollen by the gases generated by their first decomposition. The few accompanying shells are of those light kinds which frequently float on the surface of rivers, together with wood.

M. Prevost has therefore suggested that a river may have swept away the bodies of animals, and the plants which lived on its borders, or in the lakes which it traversed, and may have carried them down into the centre of the gulf into which flowed the waters impregnated with sulphate of lime. We know that the Fiume Salso in Sicily enters the sea so charged with various salts that the thirsty cattle refuse to drink of it. A stream of sulphureous water, as white as milk, descends into the sea from the volcanic mountain of Idienne, on the east of Java; and a great body of hot water, charged with sulphuric acid, rushed down from the same volcano on one occasion, and inundated a large tract of country, destroying, by its noxious properties, all the vegetation.* In like manner the Pusanibio, or "Vinegar River," of Colombia, which rises at the foot of Puracé, an extinct volcano, 7,500 feet above the level of the sea, is strongly impregnated with sulphuric and muriatic acids and with oxide of iron. We may easily suppose the waters of such streams to have properties noxious to marine animals, and in this manner the entire absence of marine remains in the ossiferous gypsum may be explained.†

There are no pebbles or coarse sand in the gypsum; a circumstance which agrees well with the hypothesis that these beds were precipitated from water holding sulphate of lime in solution, and floating the remains of different animals. The bones of land quadrupeds, however, are not confined entirely to the freshwater formation, to which the gypsum belongs; for the remains of a Palæotherium, together with some freshwater shells, have been found in a marine stratum belonging to the calcaire grossier at Beauchamp.

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* Leyde Magaz. voor Wetensch Konst en Lett., partie v. cahier i. p. 71. Cited by Rozet, Journ. de Géologie, tom. i. p. 43.

† M. C. Prevost, Submersions Itératives, &c. Note 23.

In the gypsum the remains of about fifty species of quadrupeds have been found, all extinct, and nearly four-fifths of them belonging to a division of the order Pachydermata, which is now represented by only four living species; namely, three tapirs and the daman of the Cape. With them a few carnivorous animals are associated, among which are a species of fox and gennet. Of the *Rodentia*, a dormouse and a squirrel; of the *Insectivora*, a bat; and of the *Marsupialia* (an order now confined to America, Australia, and some contiguous islands), an opossum, have been discovered.

Of birds, about ten species have been ascertained, the skeletons of some of which are entire. None of them are referable to existing species.* The same remark applies to the fish, according to MM. Cuvier and Agassiz, as also to the reptiles. Among the last are crocodiles and tortoises of the genera *Emys* and *Trionix*.

The tribe of land quadrupeds most abundant in this formation is such as now inhabits alluvial plains and marshes, and the banks of rivers and lakes, a class most exposed to suffer by river inundations. Whether the disproportion of carnivorous animals can be ascribed to this cause, or whether they were comparatively small in number and dimensions, as in the indigenous fauna of Australia, when first known to Europeans, is a point on which it would be rash, perhaps, to offer an opinion in the present state of our knowledge.

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* Cuvier, Oss. Foss., tom. iii. p. 255.

Upper marine and upper freshwater formations. — In addition to the several formations already enumerated, there are still two others, one usually called the upper marine, and the other the third or upper freshwater, which do not seem to have been going on simultaneously with the preceding groups. It seems probable that the deposits of the Paris basin, before described, had subsided to a certain extent, so that the sea prevailed exclusively for a time, and a deposit, chiefly formed of micaceous and quartzose sand, eighty feet thick, with marine shells, was superimposed on the older formations. After this subsidence, and when, perhaps, the gulf or estuary had been silted up with sand, another freshwater formation was superimposed. At this period a great number of marshes and shallow lakes seem to have existed, like those which frequently overspread the newest parts of great deltas. In these lakes many layers of marl, with beds of flint or of siliceous nodules, were formed, and *Charæ*, plants which now grow in the English lakes, and at considerable depths at the bottom of the great lakes of northern Italy, left their stems and seed-vessels, which are imbedded both in marl and flint, together with freshwater shells. Some of the siliceous rocks of this formation are used extensively for millstones.

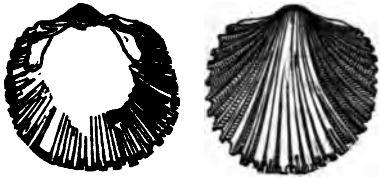
That oscillations of level occurred before the deposition of the upper marine formation seems confirmed by the fact that rolled blocks of calcaire grossier and calcaire siliceux, pierced by perforating shells belonging to no less than fifteen species, have been found in the upper marine sand. This reduction of portions of the older rocks, some of them freshwater, into fragments, implies that they had been exposed to denudation before some of the newer strata, in which the drilled blocks are now buried, were thrown down. The country may have risen in one part while it was depressed in another, as happened in the delta of the Indus in the year 1819.

Between the gypsum of the Paris basin and the upper marine sands a thin bed of oysters is found, which is spread over a remarkably wide area. From the manner in which they lie, it is inferred that they did not grow on the spot, but that some current swept them away from a bed of oysters formed in some other part of the bay. The strata of sand which immediately repose on the oyster-bed are quite destitute of organic remains; and nothing is more common in the Paris basin, and in other formations, than alternations of shelly beds with others entirely devoid of them. The temporary extinction and renewal of animal life at successive periods have been rashly inferred from such phenomena, which may nevertheless be explained, as M. Prevost justly remarks, without appealing to any such extraordinary revolutions in the state of the animate creation. A current one day scoops out a channel in a bed of shelly sand and mud, and the next day, by a slight alteration of its course, ceases to prey upon the same bank. It may then become charged with sand unmixed with shells, derived from some dune, or brought down by a river. In the course of ages an indefinite number of transitions from shelly strata to those without shells may thus be caused.

Having now given a rapid sketch of the different groups of the Paris basin, I may observe generally that they all belong to the Eocene epoch, although the entire series must doubtless have required an immense lapse of ages for its accumulation. The shells of the different freshwater groups, constituting at once some of the lowest and uppermost members of the series, are nearly all referable to the same species and the discordance between the marine testacea of the calcaire grossier and the upper marine sands is not considerable.

A curious observation has been made by M. Deshayes, in reference to the changes which one species, the *Cardium porulosum*, has undergone during the long period of its existence in the Paris basin. Different varieties of this *Cardium* are characteristic of different strata. In the older sand of the Soissonais (a marine formation underlying the regular beds of the calcaire grossier), this shell acquires but a small volume, and has many peculiarities, which disappear in the lowest beds of the calcaire grossier. In these the shell attains its full size, and many distinctive characters, which are again modified in the uppermost beds of the calcaire grossier; and these last modifications of form are preserved throughout the whole of the "upper marine" series.*

Fig. 155.



Cardium porulosum. Paris and London basins.

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* Coquilles caractérist. des Terrains, 1831.

CHAPTER XVI.

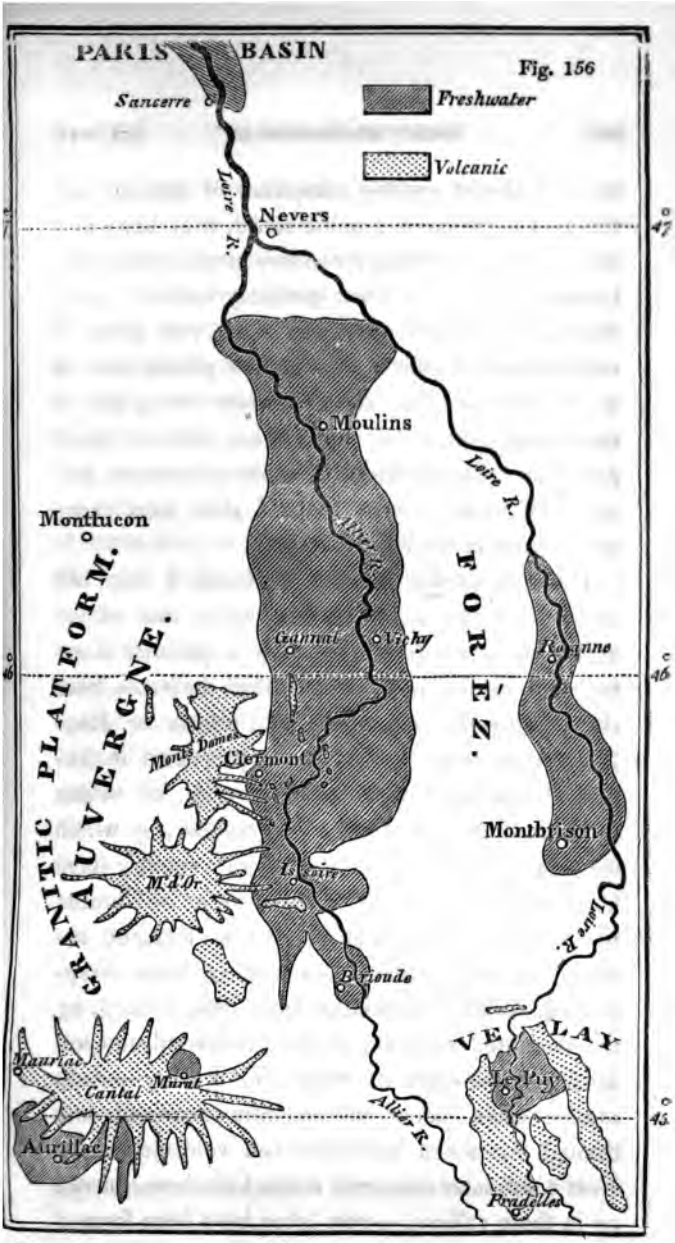
EOCENE FRESHWATER FORMATIONS.

Lacustrine strata of Auvergne. — Great series of geographical changes since the land emerged from the sea. — Tertiaryred sand stone. — Mineral character an uncertain test of age. — Marls containing Cypris. — Oolite of Eocene period. — Indusial limestone, and its origin. — Freshwater strata of the Cantal, calcareous and siliceous. — Resemblance of the white limestone and flints to chalk. — Various proofs of the gradual deposition of dense masses of strata.

In the account given in the last chapter of the tertiary strata of the Paris basin, it was shown that some members of that remarkable series of deposits were of freshwater origin. I shall now describe other formations in central France, which are very analogous in their fossils, and have been, in like manner, accumulated in large bodies of fresh water.

The strata alluded to are those of the lacustrine basins of Auvergne, Cantal, and Velay, the sites of which may be seen in the annexed map. They appear to be the monuments of ancient lakes, which, like some of those now existing in Switzerland, once occupied the depressions in a mountainous region, and have been each fed by one or more rivers and torrents. The country where they

Fig. 156


PARIS BASIN
Sancerre
Freshwater
Volcanic
Loire R.
Nevers
47°
Moulins
Loire R.
Monthucon
GRANITIC PLATFORM.
AUVERGNE.
Allier R.
FOREZ.
Gannat
Vichy
Roanne
46°
Monts Domes
Clermont
Montbrison
M.t d'Or
Issoire
Loire R.
Brioude
VELAY
Mauriac
Murat
Cantal
Le Puy
Allier R.
45°
Aurillac
Pradelles

occur is almost entirely composed of granite and different varieties of granitic schist, with here and there a few patches of secondary strata, much dislocated, and which have probably suffered great denudation. There are also some vast piles of volcanic matter (see the map), the greater part of which is newer than the freshwater strata, and is sometimes seen to rest upon them, while a small part has evidently been of contemporaneous origin. Of these igneous rocks I shall treat more particularly in the next volume.

Before entering upon any details, I may observe, that the study of this region and of the others above alluded to possess a peculiar interest, very distinct in kind from that derivable from the investigation either of the Parisian or English tertiary strata. For we are presented in Auvergne with the evidence of a series of events of astonishing magnitude and grandeur, by which the original form and features of the country have been greatly changed, yet never so far obliterated but that they may still, in part at least, be restored in imagination. Great lakes have disappeared, — lofty mountains have been formed, by the reiterated emission of lava, preceded and followed by showers of sand and scoriæ, — deep valleys have been subsequently furrowed out through masses of lacustrine and volcanic origin, — at a still later date, new cones have been thrown up in these valleys, — new lakes have been formed by the damming up of rivers, — and more than one creation of quadrupeds, birds, and plants, have followed in succession; yet the region has preserved from first to last its geographical identity; and we can still recall to our thoughts its external condition and physical structure before these wonderful vicissitudes began, or while a part only of the whole had been completed. There was first a period when the spacious lakes, of which we still may trace the boundaries, lay at the foot of mountains of moderate elevation, unbroken by the bold peaks and precipices of Mont Dor, and unadorned by the picturesque outline of the Puy de Dome, or of the volcanic cones and craters now covering the granitic platform. During this earlier scene of repose deltas were slowly formed; beds of marl and sand, several hundred feet thick, deposited; siliceous and calcareous rocks precipitated from the waters of mineral springs; shells and insects imbedded, together with the remains of the crocodile and tortoise, the eggs and bones of water birds, and the skeletons of quadrupeds, some of them belonging to the same genera as those entombed in the gypsum of Paris. To this tranquil condition of the surface succeeded the era of volcanic eruptions, when the lakes were drained, and when the fertility of the mountainous district was probably enhanced by the igneous matter ejected from below, and poured down upon the more sterile granite. During these changes, which appear to have taken place in the Miocene epoch, the mastodon, rhinoceros, elephant, tapir, hippopotamus, together with the ox, various kinds of deer, the bear, hyæna, and many beasts of prey, ranged the forest, or pastured on the plain, and were occasionally overtaken by a fall of burning cinders, or buried in flows of mud, such as accompany volcanic eruptions. Lastly, these quadrupeds became extinct, and gave place to the existing creation. There are no signs, during the whole time required for this series of events, of the sea having intervened, nor of any denudation which may not have been accomplished by currents in the different lakes, or by rivers and floods accompanying repeated earthquakes, during which the levels of the district have in some places been materially modified, and perhaps the whole upraised relatively to the surrounding parts of France.

Auvergne.—The most northern of the freshwater groups is situated in the valley-plain of the Allier, which lies within the department of the Puy de Dome, being the tract which went formerly by the name of the Limagne d'Auvergne. It is inclosed by two parallel primitive ranges,—that of the Forèz, which divides the waters of the Loire and Allier, on the east; and that of the Monts Domes, which separates the Allier from the Sioule, on the west.* The average breadth of this tract is about twenty miles; and it is for the most part composed of nearly horizontal strata of sand, sandstone, calcareous marl, clay, and limestone, none of which observe a fixed and invariable order of superposition. The ancient borders of the lake, wherein the freshwater strata were accumulated, may generally be traced with precision, the granite and other ancient rocks rising up boldly from the level country. The actual junction, however, of the lacustrine and granitic beds is rarely seen, as a small valley usually intervenes between them. The freshwater strata may sometimes be seen to retain their horizontality within a very slight distance of the border-rocks, while in some places they are inclined, and in a few instances vertical. The principal divisions into which the lacustrine series may be separated are the following: — 1st, Sandstone, grit, and conglomerate, including red marl and red sandstone. 2dly, Green and white foliated marls. 3dly, Limestone or travertin, often oolitic. 4thly, Gypseous marls.

1. *a. Sandstone and conglomerate.* — Strata of sand and gravel, sometimes bound together into a solid rock, are found in great abundance around the confines of the lacustrine basin, containing, in different places, pebbles of all the ancient rocks of

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* Scrope, Geology of Central France, p. 15.

the adjoining elevated country; namely, granite, gneiss, mica-schist, clay-slate, porphyry, and others. But these strata do not form one continuous band around the margin of the basin, being rather disposed like the independent deltas which grow at the mouths of torrents along the borders of existing lakes.

At Chamalieres, near Clermont, we have an example of one of these deltas, or littoral deposits, of local extent, where the pebbly beds slope away from the granite, as if they had formed a talus beneath the waters of the lake near the steep shore. A section of about fifty feet in vertical height has been laid open by a torrent, and the pebbles are seen to consist throughout of rounded and angular fragments of granite, quartz, primary slate, and red sandstone; but without any intermixture of those volcanic rocks which now abound in the neighbourhood, and which could not have been there when the conglomerate was formed. Partial layers of lignite and pieces of wood are found in these beds.

At some localities on the margin of the basin quartzose grits are found; and, where these rest on granite, they are sometimes formed of separate crystals of quartz, mica, and felspar, derived from the disintegrated granite, the crytals having been subsequently bound together by a siliceous cement. In these cases the granite seems regenerated in a new and more solid form; and so gradual a passage takes place between the rock of crystalline and that of mechanical origin, that we can scarcely distinguish where one ends and the other begins.

In the hills called the Puy de Jussat and La Roche, we have the advantage of seeing a section continuously exposed for about 700 feet in thickness. At the bottom are foliated marls, white and green, about 400 feet thick; and above, resting on the marls, are the quartzose grits, cemented by calcareous matter, which is sometimes so abundant as to form imbedded nodules. These sometimes constitute spheroidal concretions six feet in diameter, and pass into beds of solid limestone, resembling the Italian travertins, or the deposits of mineral springs. This section is close to the confines of the basin; so that the lake must here have been filled up near the shore with fine mud, before the coarse superincumbent sand was introduced. There are other cases where sand is seen below the marl.

1. *b. Red marl and sandstone.*—But the most remarkable of the arenaceous groups is one of red sandstone and red marl, which are identical in all their characters with the secondary *New Red sandstone* and marl of England. In these secondary rocks the red ground is sometimes variegated with light greenish spots, and the same may be

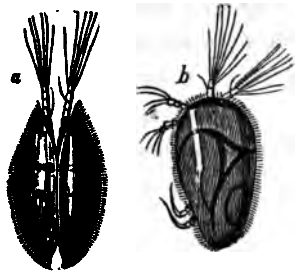
seen in the tertiary formation of freshwater origin at Coudes, on the Allier. The marls are sometimes of a purplish-red color, as at Champheix, and are accompanied by a reddish limestone, like the well-known "cornstone," which is associated with the Old Red sandstone of English geologists. The red sandstone and marl of Auvergne have evidently been derived from the degradation of gneiss and mica-schist, which are seen *in situ* on the adjoining hills, decomposing into a soil very similar to the tertiary red sand and marl. We also find pebbles of gneiss, mica-schist, and quartz in the coarser sandstones of this group, clearly pointing to the parent rocks from which the sand and marl are derived. The red beds, although destitute themselves of organic remains, pass upwards into strata containing Eocene fossils, and are certainly an integral part of the lacustrine formation. From this example the student will learn how small is the value of mineral character alone, as a test of the relative age of rocks.

2. *Green and white foliated marls.* — The same primary rocks of Auvergne, which, by the partial degradation of their harder parts, gave rise to the quartzose grits and conglomerates before mentioned, would, by the reduction of the same materials into powder, and by the decomposition of their felspar, mica, and hornblende, produce aluminous clay; and, if a sufficient quantity of carbonate of lime

was present, calcareous marl. This fine sediment would naturally be carried out to a greater distance from the shore, as are the various finer marls now deposited in Lake Superior. And as, in the American lake, shingle and sand are annually amassed near the northern shores, so in Auvergne the grits and conglomerates before mentioned were evidently formed near the borders.

The entire thickness of these marls is unknown; but it certainly exceeds, in some places, 700 feet. They are, for the most part, either light-green or white, and usually calcareous. They are thinly foliated, — a character which frequently arises from the innumerable thin plates or scales of that small animal called *Cypris;* a genus which comprises several species, of which some are recent, and may

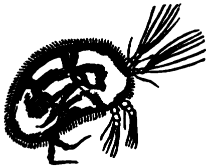
Fig. 157.



Cypris unifasciata, a living species, greatly magnified.

a. Upper part. *b.* Side view of the same.

Fig. 158.



Cypris vidua, a living species, greatly magnified.*

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* See Desmarest's Crustacea, plate 55.

be seen swimming swiftly through the waters of our stagnant pools and ditches. The antennæ, at the end of which are fine pencils of hair, are the principal organs of motion, and are seen to vibrate with great rapidity. This animal resides within two small valves, not unlike those of a bivalve shell, and moults its integuments annually, which the conchiferous mollusks do not. This circumstance may partly explain the countless myriads of the shells of *Cypris* which were shed in the ancient lakes of Auvergne, so as to give rise to divisions in the marl as thin as paper, and that, too, in stratified masses several hundred feet thick A more convincing proof of the tranquillity and clearness of the waters, and of the slow and gradual process by which the lake was filled up with fine mud, cannot be desired. But we may easily suppose that, while this fine sediment was thrown down in the deep and central parts of the basin, gravel, sand, and rocky fragments were hurried into the lake and deposited near the shore, forming the group described in the preceding section.

Not far from Clermont, the green marls, containing the *cypris* in abundance, approach to within a few yards of the granite which forms the borders of the basin. The occurrence of these marls so near the ancient margin may be explained by considering that, at the bottom of the ancient lake, no coarse ingredients were deposited in spaces intermediate between the points where rivers and torrents entered, but finer mud only was drifted there by

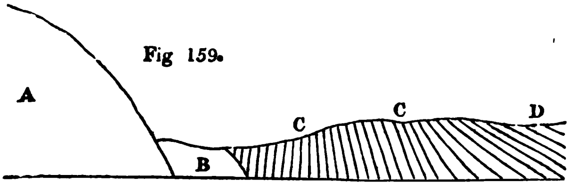


Fig 159.

Vertical strata of marl, at Champradelle, near Clermont.

A. Granite. B. Space of sixty feet, in which no section is seen.
C. Green marl, vertical and inclined. D. White marl.

currents. The *verticality* of some of the beds in the above section bears testimony to considerable local disturbance subsequent to the deposition of the marls; but such inclined and vertical strata are very rare.

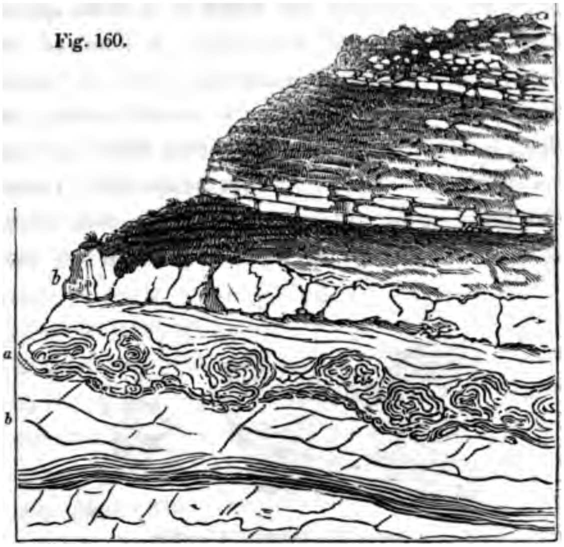
3. *Limestone, travertin, oolite.* — Both the preceding members of the lacustrine deposit, the marls and grits, pass occasionally into limestone. Sometimes only concretionary nodules abound in them; but these, where there is an increase in the quantity of calcareous matter, unite into regular beds.

On each side of the basin of the Limagne, both on the west at Gannat, and on the east at Vichy, a white oolitic limestone is quarried. At Vichy, the oolite resembles our Bath stone in appearance and beauty; and, like it, is soft when first taken from the quarry, but soon hardens on exposure to the air. At Gannat, the stone contains land-shells and bones of quadrupeds, resembling those of the Paris gypsum. At Chadrat, in the hill of La Serre, the limestone is pisolitic, the small spheroids combining both the radiated and concentric structure.

Indusial limestone. — There is another remarkable form of freshwater limestone in Auvergne, called "indusial," from the cases, or *indusiæ*, of caddis-worms (the larvæ of *Phryganea*); great heaps of which have been incrusted, as they lay, by carbonate of lime, and formed into a hard travertin. The rock is sometimes purely calcareous, but there is occasionally an intermixture of siliceous matter. Several beds of it are frequently seen, either in continuous masses, or in concretionary nodules, one upon another, with layers of marl interposed. The annexed drawing (Fig. 160.) will show the manner in which one of these indusial beds (*a*) is laid open at the surface, between the marls (*b b*), near the base of the hill of Gergovia; and affords, at the same time, an example of the extent to which the lacustrine strata, which must once have filled a hollow, have been denuded, and shaped out into hills and valleys, on the site of the ancient lakes.

We may often observe in ourponds the *Phryganea* (or May-fly), in its caterpillar state, covered with small freshwater shells, which they have the

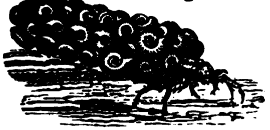
Fig. 160.



Bed of indusial limestone, interstratified with freshwater marl, near Clermont, (Kleinschrod).

power of fixing to the outside of their tubular cases, in order, probably, to give them weight and strength. The individual figured in the annexed cut, which belongs to a species very abundant in England, has happened to cover its case with shells of a small *Planorbis*. In the same manner a large species of caddis-worm, which swarmed in the

Fig. 161



Larva of recent Phryganea.[*]

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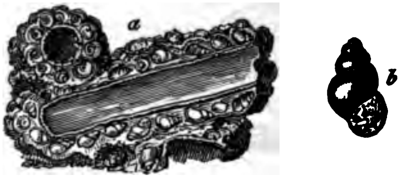
[*] I believe that the British specimen here figured is *P rhombica*, Linn.

Eocene lakes of Auvergne, was accustomed to attach to its dwelling the shells of a small spiral univalve of the genus *Paludina.* A hundred of these minute shells are sometimes seen arranged around one tube, part of the central cavity of which is often empty, the rest being filled up with thin concentric layers of travertin. The cases have been thrown together confusedly, and often lie, as in Fig. 162., at right angles one to the other. When we consider that ten or twelve tubes are packed within the compass of a cubic inch, and that some single strata of this limestone are six feet thick, and may be traced over a considerable area, we may form some idea of the countless number of insects and mollusca which contributed their integuments and shells to compose this singularly constructed rock. It is unnecessary to suppose that the *Phryganeæ* lived on the spots where their cases are now found; they may have multiplied in the shallows near the

Fig. 162.



a. Indusial limestone of Auvergne.
b. Fossil *Paludina* magnified.

margin of the lake, or in the streams by which it was fed, and their cases may have been drifted by a current far into the deep water.

In the summer of 1837, when examining, in company with Dr. Beck, a small lake near Copenhagen, I had an opportunity of witnessing a beautiful exemplification of the manner in which the tubular cases of Auvergne were probably accumulated. This lake, called the Fuure-Soe, occurring in the interior of Seeland, is about twenty English miles in circumference, and in some parts 200 ft. in depth. Round the shallow borders an abundant crop of reeds and rushes may be observed, covered with the indusiæ of the *Phryganea grandis* and another species, to which shells are attached. The plants which support them are *Scirpus lacustris* and *Arundo phragmitis*, but chiefly the former. In summer, especially in the month of June, a violent gust of wind sometimes causes a current by which these plants are torn up by the roots, washed away, and floated off in long bands, more than a mile in length, into deep water. The *Cypris* swarms in the same lake; and calcareous springs alone are wanting to form extensive beds of indusial limestone, like those of Auvergne.

4. *Gypseous marls.* — More than fifty feet of thinly laminated gypseous marls, exactly resembling those in the hill of Montmartre, at Paris, are worked for gypsum at St. Romain on the

right bank of the Allier. They rest on a series of green cypriferous marls which alternate with grit, the united thickness of this inferior group being seen, in a vertical section on the banks of the river, to exceed 250 feet.

General arrangement and origin of the freshwater formations of Auvergne. — The relations of the different groups above described cannot be learnt by the study of any one section; and the geologist who sets out with the expectation of finding a fixed order of succession may perhaps complain that the different parts of the basin give contradictory results. The arenaceous division, the marls, and the limestone, may all be seen in some places to alternate with each other; yet it can, by no means, be affirmed that there is no order of arrangement. The sands, sandstone, and conglomerate, constitute in general a littoral group; the foliated white and green marls, a contemporaneous central deposit; and the limestone is for the most part subordinate to the newer portions of both. The uppermost marls and sands are more calcareous than the lower; and we never meet with calcareous rocks covered by a considerable thickness of quartzose sand or green marl. From the resemblance of the limestones to the Italian travertins, we may conclude that they were derived from the waters of mineral springs, — such springs as even now exist in Auvergne, and which may be seen rising up through the granite, and precipitating travertin. They are sometimes thermal, but this character is by no means constant.

It seems that, when the ancient lake of the Limagne first began to be filled with sediment, no volcanic action had yet produced lava and scoriæ on any part of the surface of Auvergne. No pebbles, therefore, of lava were transported into the lake, — no fragments of volcanic rocks imbedded in the conglomerate. But at a later period, when a considerable thickness of sandstone and marl had accumulated, eruptions broke out, and lava and tuff were deposited, at some spots, alternately with the lacustrine strata. It is not improbable that cold and thermal springs, holding different mineral ingredients in solution, became more numerous during the successive convulsions attending this development of volcanic agency, and thus deposits of carbonate and sulphate of lime, silex, and other minerals, were produced. Hence these minerals predominate in the uppermost strata. The subterranean movements may then have continued until they altered the relative levels of the country, and caused the waters of the lakes to be drained off, and the further accumulation of regular freshwater strata to cease.

We may easily conceive a similar series of events to give rise to analogous results in any modern basin, such as that of Lake Superior, for example, where numerous rivers and torrents are carrying down the detritus of a chain of mountains into the lake. The transported materials must be arranged according to their size and weight, the coarser near the shore, the finer at a greater distance from land; but in the gravelly and sandy beds of Lake Superior no pebbles of modern volcanic rocks can be included, since there are none of these at present in the district. If igneous action should break out in that country, and produce lava, scoriæ, and thermal springs, the deposition of gravel, sand, and marl might still continue as before; but, in addition, there would then be an intermixture of volcanic gravel and tuff, and of rocks precipitated from the waters of mineral springs.

Although the freshwater strata of the Limagne approach generally to a horizontal position, the proofs of local disturbance are sufficiently numerous and violent to allow us to suppose great changes of level since the lacustrine period. We are unable to assign a northern barrier to the ancient lake, although we can still trace its limits to the east, west, and south, where they were formed of bold granitic eminences. Nor need we be surprised at our inability to restore entirely the physical geography of the country after so great a series of volcanic eruptions; for it is by no means improbable that one part of it, the southern for example, may have been moved upwards bodily, while others remained at rest, or even suffered a movement of depression.

Cantal. — A freshwater formation, very analogous to that of Auvergne, is situated in the department of Haute Loire, near the town of Le Puy, in Velay, and another occurs near Aurillac, in Cantal. The leading feature of the formation last mentioned, as distinguished from those of Auvergne and Velay, is the immense abundance of silex associated with calcareous marls and limestone.

The whole series may be separated into two divisions; the lower, composed of gravel, sand, and clay, such as might have been derived from the wearing down and decomposition of the granitic schists of the surrounding country; the upper system, consisting of siliceous and calcareous marls, contains subordinately gypsum, silex, and limestone.

The resemblance of the freshwater limestone of the Cantal, and its accompanying flint, to the upper chalk of England, is very instructive, and well calculated to put the student upon his guard against relying too implicitly on mineral character alone as a safe criterion of relative age.

When we approach Aurillac from the west, we pass over great heathy plains, where the sterile mica schist is barely covered with vegetation.

Near Ytrac, and between La Capelle and Viscamp, the surface is strewed over with loose broken flints, some of them black in the interior, but with a white external coating; others stained with tints of yellow and red, and in appearance precisely like the flint gravel of our chalk districts. When heaps of this gravel have thus announced our approach to a new formation, we arrive at length at the escarpment of the lacustrine beds. At the bottom of the hill which rises before us, we see strata of clay and sand resting on mica-schist; and above, in the quarries of Belbet, Leybros, and Bruel, a white limestone, in horizontal strata, the surface of which has been hollowed out into irregular furrows, since filled up with broken flint, marl, and dark vegetable mould. In these cavities we recognise an exact counterpart to those which are so numerous on the furrowed surface of our own white chalk. Advancing from these quarries, along a road made of the white limestone, which reflects as glaring a light in the sun, as do our roads composed of chalk, we reach, at length, in the neighbourhood of Aurillac, hills of limestone and calcareous marl, in horizontal strata, separated in some places by regular layers of flint in nodules, the coating of each nodule being of an opaque white color, like the exterior of the flinty nodules of our chalk.

It will be remembered that the siliceous stone of Bilin, called *tripoli*, is a freshwater deposit, and has been shown, by Ehrenberg, to be of infusorial origin (see p. 52.). What is true of the Bohemian flint and opal, where the beds attain a thickness of fourteen feet, may also, perhaps, be found to hold good respecting the silex of Aurillac, which may also have been immediately derived from the minute cases of microscopic animalcules. But even if this conclusion be established, the abundant supply both of siliceous, calcareous, and gypseous matter, which the ancient lakes of France received, may have been connected with the subterranean volcanic agency of which those regions were so long the theatre, and which may have impregnated the springs with mineral matter, even before the great outbreak of lava. It is well known that the hot springs of Iceland, and many other countries, contain silex in solution; and it has been lately affirmed, that steam at a high temperature is capable of dissolving quartzose rocks, without the aid of any alkaline or other flux.*

Travellers not unfrequently mention, in their accounts of India, Australia, and other distant lands, that they have seen chalk with flints, which they have assumed to be of the same age as the Cretaceous system of Europe. A hasty observation of the white limestone and flint of Aurillac might convey the same idea; but when we turn from the mineral aspect and composition to the organic remains, we find in the flints of the Cantal the seed-vessels of the freshwater *Chara*, instead of the marine zoophytes so abundantly imbedded in chalk flints; and in the limestone we meet with shells of *Limnea*, *Planorbis*, and other lacustrine genera, instead of the oyster, terebratula, and echinus of the Cretaceous period.

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* See Proceedings of Roy. Soc., No. 44. p. 233.

Proofs of gradual deposition. — Some sections of the foliated marls in the valley of the Cer, near Aurillac, attest, in the most unequivocal manner, the extreme slowness with which the materials of the lacustrine series were amassed. In the hill of Barrat, for example, we find an assemblage of calcareous and siliceous marls; in which, for a depth of at least sixty feet, the layers are so thin, that thirty are sometimes contained in the thickness an of inch; and when they are separated, we see preserved in every one of them the flattened stems of *Charæ*, or other plants, or sometimes myriads of small *Paludinæ* and other freshwater shells. These minute foliations of the marl resemble precisely some of the recent laminated beds of the Scotch marl lakes, and may be compared to the pages of a book, each containing a history of a certain period of the past. The different layers may be grouped together in beds from a foot to a foot and a half in thickness, which are distinguished by differences of composition and color, the tints being white, green, and brown. Occasionally there is a parting layer of pure flint, or of black carbonaceous vegetable matter, about an inch thick, or of white pulverulent marl. We find several hills in the neighbourhood of Aurillac composed of such materials, for the height of more than 200 feet from their base, the whole sometimes covered by rocky currents of trachytic or basaltic lava.*

Thus wonderfully minute are the separate parts of which some of the most massive geological monuments are made up! When we desire to classify, it is necessary to contemplate entire groups of strata in the aggregate; but if we wish to understand the mode of their formation, and to explain their origin, we must think only of the minute subdivisions of which each mass is composed. We must bear in mind how many thin leaf-like seams of matter, each containing the remains of myraids of testacea and plants, frequently enter into the composition of a single stratum, and how vast a succession of these strata unite to form a single group! We must remember, also, that piles of volcanic matter, like the Plomb du Cantal, which rises in the immediate neighbourhood of Aurillac, are themselves equally the result of successive accumulation, consisting of reiterated sheets of lava, showers of scoriæ, and ejected fragments of rock. — Lastly, we must not forget that continents and mountain-chains, colossal as are their dimensions, are nothing more than an assemblage of many such igneous and aqueous groups, formed in succession during an indefinite lapse of ages, and superimposed upon each other.

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* Lyell and Murchison, sur les Dépôts Lacust. Tertiaires du Cantal, &c. Ann. des Sci. Nat. Oct. 1829.

CHAPTER XVII.

CRETACEOUS GROUP.

White chalk — Its marine origin shown by fossil shells — Extinct genera of cephalopoda — Sponges and corals in the chalk — No terrestrial or fluviatile shells, no land plants — Supposed origin of white chalk from decomposed corals — Single pebbles, whence derived — Cretaceous coral-reef in Denmark — Maestricht beds and fossils — Origin of flint in chalk — Wide area covered by chalk — Green-sand formation and fossils — Origin of — Period of emergence from the sea — Difference of the chalk of the north and south of Europe — Hippurites — Nummulites — Altered lithological character of cretaceous formation in Spain and Greece — Terminology.

The group which succeeds to the tertiary strata in the descending order has been called Cretaceous or chalky, because it consists in part of that remarkable white earthy limestone called chalk (*creta*). With this limestone, however, are usually associated other deposits of sand, marl, and clay, called the Green-sand formation, because some of its sands are remarkable for their bright green color.

The following is the manner in which the Cretaceous strata of the South of England have been subdivided: —

Cretaceous group.	1. Chalk formation.	a. soft white chalk, with flints	united thickness from 600 to 1000 feet.*
		b. hard white chalk, with few or no flints	
		c. chalk marl	
	2. Green-sand formation.	a. upper green-sand	thickness 30 to 100 feet.
		b. Gault, or blue marl,	10 to 150 ft.
		c. lower green-sand and iron-sand, with occasional limestone	250.†

The accompanying section (Fig. 163.) will show the manner in which the tertiary strata of the London and Paris basins, as they are called, rest upon the Chalk; and how the white chalk, in its turn, reposes throughout this region upon the Green-sand formation.

I shall now speak first of the Chalk, its fossils, and probable origin; and then say something of the Green-Sand; after which I shall point out the probable relations of the Chalk and Green-Sand to each other.

White Chalk.—The white chalk used in writing consists almost purely of carbonate of lime. Although usually soft, this substance passes in some districts, by a gradual change, into a solid stone used for building. The stratification is often obscure, except where rendered distinct by alternating layers of flint. These layers are from two to four feet distant from each other, and from three

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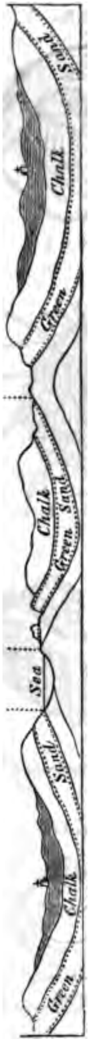
* Conybeare, Outlines, &c., p. 85.

† Fitton, Geol. Trans., Second Series, vol. iv. p. 319.

Fig. 163.



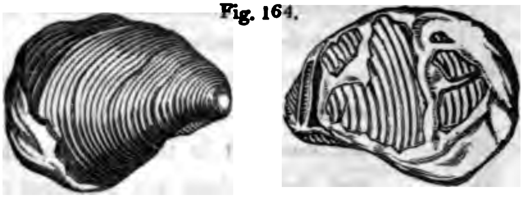
Section from Hertfordshire, in England, to Sens, in France.

to six inches in thickness, occasionally in continuous beds, but more frequently in nodules.

The annexed figures represent some few of the fossil shells which are abundant in the white chalk, and these alone are sufficient to prove its marine origin. Several of them, such as the *Terebratulæ* (see Figs. 168. 170, 171, 172.), are known to live at the bottom of the sea, where the water is tranquil and of some depth. The *Catillus* (Fig. 164.) may be pointed out as a form, which, so far as our present information extends, became extinct at the close of the cretaceous period, being never met with in any tertiary stratum, or in a living state. Among other equally conspicuous forms of fossil mollusca belonging to the cretaceous group, and foreign to the tertiary and recent periods, may be mentioned the *Belemnite*, *Ammonite*, *Baculite*, and *Turrilite* of the family *Cephalopoda*, to which the living Cuttle-fish and Nautilus belong.

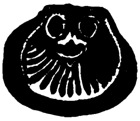
FOSSILS OF THE WHITE CHALK.

Fig. 164.



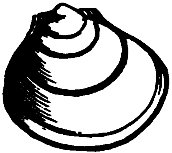
Catillus Cuvieri. (Syn. *Inoceramus Cuvieri*, Sow.)

Fig. 165.



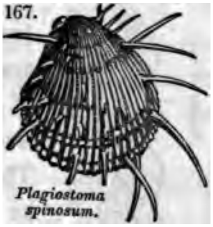
Crania Parisiensis,
inferior or attached
valve.

Fig. 166.



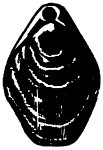
Plagiostoma
Hoperi.

Fig. 167.



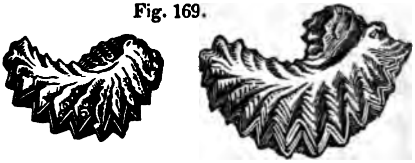
Plagiostoma
spinosum.

Fig. 168.



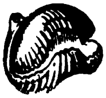
Terebratula
Defrancii.

Fig. 169.



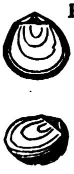
Ostrea carinata.
Chalk Marl and Upper Green-sand.

Fig. 170.



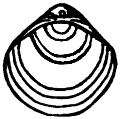
Terebratula
octoplicata.
(*Var. of T. plicatilis.*)

Fig. 171.



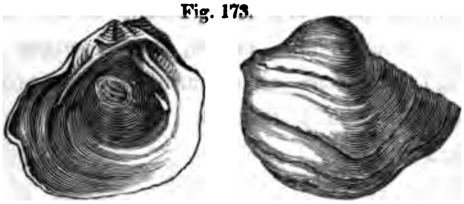
Terebratula pumilus.
(*Magas pumilus*, Sow.)

Fig. 172.



Terebratula
carnea.

Fig. 173.

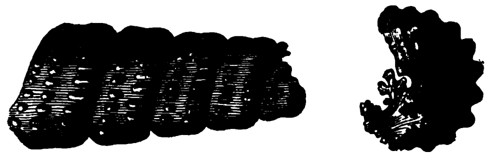


Ostrea vesicularis. (*Gryphæa globosa*, Sow.)
Also in Upper Green-sand.

FOSSIL CEPHALOPODA OF EXTINCT GENERA.

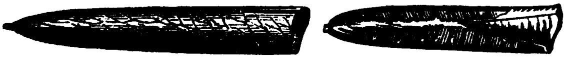
Cretaceous Period.

Fig. 174.



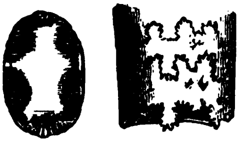
a. *Turrilites costatus.* Chalk-marl.
b. *Same, showing the indented border of the partition of the chambers.*

Fig. 175.



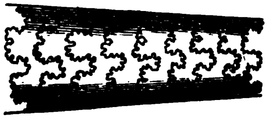
a. *Belemnites mucronatus.* } White Chalk and Upper Green-sand.
b. *Same, internal structure.*

Fig. 176.



Portion of Baculites Faujasii.
White Chalk.

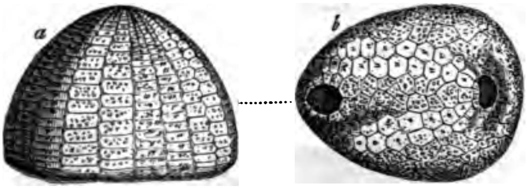
Fig. 177.



Portion of Baculites anceps.
White Chalk.

One of these, the *Belemnite*, like the bone of the common cuttle-fish, was an internal shell. Besides these, there are other fossils in the chalk, such as sea-urchins, corals, and sponges (see Figures), which are alike marine. They are dispersed indifferently through the soft chalk and the hard flint.

Fig. 178.



Ananchytes ovatus.

a. side view.

b. bottom of the shell, on which both the oral and anal apertures are placed; the anal being to the left, and more round.

Fig. 179.

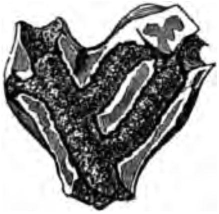
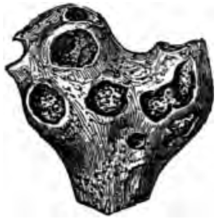


Fig. 180.



A branching sponge in a flint from the chalk.[*]

To some of these inclosed zoophytes many flints owe their irregular forms, as in the flint represented in Fig. 180., where the hollows on the exterior are caused by the branches of a sponge,

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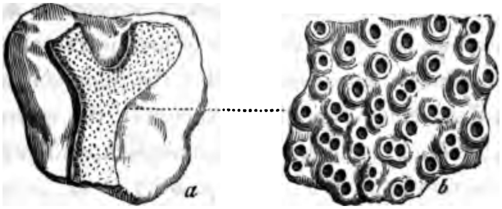
[*] From the collection of Mr. Bowerbank.

Fig. 181.



Eschara disticha.

a. natural size. *b.* portion magnified.

which is seen on breaking open the flint. (See Fig. 179.)

With these fossils the remains of fishes and crustacea are not uncommon; but we meet with no bones of land animals, nor any terrestrial or fluviatile shells, nor any plants, except pieces of drift-wood and sea-weed, and scarcely ever any sand or pebbles. All the appearances concur in leading us to believe that this deposit was formed in a sea of some depth, far from land, and at a time when the fauna of this part of the globe was perfectly distinct from that of the tertiary period.

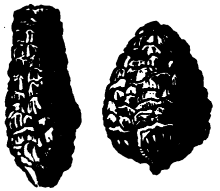
Origin of the White Chalk. — Having then come to the conclusion, that the chalk was formed in an open sea of some depth; we may next inquire, in what manner so large a quantity of this peculiar white substance could have accumulated over an area many hundred miles in diameter, and some of the extreme points of which are distant, as we shall see in the sequel, more than 1000 geographical miles from each other.

It was remarked in an early part of this volume, that some even of that chalk which appears to an ordinary observer quite destitute of organic remains, is nevertheless, when seen under the microscope, full of fragments of corals and sponges; the valves of *Cytherina*, the shells of foraminifera, and still more minute infusoria. (See p. 56.)

Now it had been often suspected, before these discoveries, that white chalk might be of animal origin, even where every trace of organic structure has vanished. This bold idea was partly founded on the fact, that the chalk consisted of pure carbonate of lime, such as would result from the decomposition of testacea, echini, and corals; and partly on the passage observable between these fossils when half decomposed and chalk. But this conjecture seemed to many naturalists quite vague and visionary, until its probability was strengthened by new evidence brought to light by modern geologists.

We learn from Lieutenant Nelson, that, in the Bermuda islands, there are several basins or lagoons almost surrounded and inclosed by reefs of coral. At the bottom of these lagoons a soft white calcareous mud is formed by the decomposition of *Eschara*, *Flustra*, *Cellepora*, and other corallines. This mud, when dried, is undistinguishable from common white earthy chalk; and some portions of it, presented to the Museum of the Geological Society of London, might, after full examination, be mistaken for ancient chalk, but for the labels attached to them. About the same time Mr. C. Darwin observed similar facts in the coral islands of the Pacific; and came also to the opinion, that much of the soft white mud found at the bottom of the sea near coral reefs has passed through the bodies of worms, by which the stony masses of coral are everywhere bored; and other portions through the intestines of fishes; for certain gregarious fishes of the genus *Sparus* are visible through the clear water, browsing quietly, in great numbers, on living corals, like grazing herds of graminivorous quadrupeds. On opening their bodies, Mr. Darwin found their intestines filled with impure chalk. This circumstance is the more in point, when we recollect how the fossilist was formerly puzzled by meeting, in chalk, with certain bodies, called cones of the larch, which were afterwards recognised by Dr. Buckland to be the excrement of fish.* These spiral coprolites (see Figures), like the scales and bones of fossil fish in the chalk, are composed chiefly of phosphate of lime.

Fig. 182. Fig. 183.



Coprolites of fish called Iuloeido-copri, from the chalk.

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* Geol. Trans., Second Series, vol. iii. p. 232. plate 31. figs. 3. and 11.

Single pebbles in chalk. — The general absence of sand and pebbles in the white chalk has been already mentioned: but the occurrence here and there, in the southeast of England, of a few isolated pebbles of quartz and green-schist, some of them two or three inches in diameter, has justly excited much wonder. If these had been carried to the spots where we now find them by waves or currents from the lands once bordering the cretaceous sea, how happened it that no sand or mud were transported thither at the same time? We cannot conceive such rounded stones to have been drifted like erratic blocks by ice,* for that would imply a cold climate in the Cretaceous period; a supposition inconsistent with the luxuriant growth of large chambered univalves, numerous corals, and many fish, and other fossils of tropical forms.

Now in Keeling Island, one of those detached masses of coral which rise up in the wide Pacific, Captain Ross found a single fragment of greenstone, where every other particle of matter was calcareous; and Mr. Darwin concludes that it must have come there entangled in the roots of a large tree. He reminds us that Chamisso, the distinguished naturalist who accompanied Kotzebue, affirms, that the inhabitants of the Radack archipelago, a group of lagoon islands, in the midst of the Pacific, obtained stones for sharpening their instruments by searching the roots of trees which are cast up on the beach.*

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* See Chapters X. and XI.

It may perhaps be objected, that a similar mode of transport cannot have happened in the cretaceous sea, because fossil wood is very rare in the chalk. Nevertheless wood is sometimes met with, and in the same parts of the chalk where the pebbles are found, both in soft stone and in a silicified state in flints. In these cases it has often every appearance of having been floated from a distance, being usually perforated by boring-shells, such as the *Teredo* and *Fistulana*.†

The only other mode of transport which suggests itself is sea-weed. Dr. Beck informs me, that in the Lym-Fiord, in Jutland, the *Fucus vesiculosus* sometimes grows to the height of ten feet, and the branches rising from a single root, form a cluster several feet in diameter. When the bladders are distended, the plant becomes so buoyant as to float up loose stones several inches in diameter, and these are often thrown by the waves high up on the beach. The *Fucus giganteus* of Solander, so common in Terra del Fuego, is said by Captain Cook to attain the length of 360 feet, although the stem is not much thicker than a man's thumb. It is often met with floating at sea, with shells attached, several hundred miles from the spots where it grew. Some of these plants, says Mr. Darwin, were found adhering to large loose stones in the inland channels of Terra del Fuego, during the voyage of the Beagle in 1834; and that so firmly, that the stones were drawn up from the bottom into the boat, although so heavy that they could scarcely be lifted in by one person.* Some fossil sea-weeds have been found in the Cretaceous formation, but none, as yet, of large size.

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* Darwin, p. 549. Kotzebue's First Voyage, vol. iii. p. 155.

† Mantell, Geol. of S. E. of England, p. 96.

Cretaceous coral reef in Denmark. — Having said so much on the probable derivation of chalk from the decay of corals and shells, I may add, that in the island of Seeland, in Denmark, there is a yellow limestone intimately connected with the chalk, and containing a vast number of the same fossils, which consists of an aggregate of corals, retaining their forms as distinctly as the dead zoophytes which enter into the structure of reefs now growing in the sea. The thickness of this rock is unknown, but it has been quarried at Faxoe to the depth of forty feet. At Stevensklint, in Seeland, it is seen to rest on white chalk with flints, from which it differs greatly in appearance, and where it is covered again by another limestone, which, although of later date, agrees more nearly with the white chalk, both in fossils and mineral character. Out of 104 species of sponges, corals, and other zoophytes, collected from the limestone of Faxoe, and from the ordinary white chalk of Denmark, which agrees with that of England, no less than forty-two are common to both formations; and many of the same species of bivalve shells and echinodermata have been found in both. The Faxoe formation, however, is not only remarkable for the number and good preservation of its fossil corals, but also from the generic resemblance of many of its univalve shells to forms usually supposed to appertain chiefly or exclusively to the tertiary period. Thus, among the patelliform univalves, we find *Patella* and *Emarginula*, and among the spiral the following genera, *Cypræa*, *Oliva*, *Mitra*, *Cerithium*, *Fusus*, *Trochus*, *Triton*, *Nassa*, and *Bulla*.

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* Darwin, p. 303. (For full reference see p. 168.)

The *species*, however, do not agree with those of the tertiary strata, and are associated with cephalopoda of those extinct families before mentioned as characteristic of the cretaceous, and foreign to the tertiary epoch; as, for example, the *Ammonite*, *Belemnite*, and *Baculite:* two species, the *Belemnites mucronatus* (Fig. 175.), and the *Baculites Faujasii* (Fig. 176.), being common to the Faxoe beds and the white chalk.

From these facts, we may conclude that the

Faxoe limestone was formed in the cretaceous sea, in a spot favorable for the multiplication of stony corals and univalve shells; and as some small portions of the rock consist of white earthy chalk, this latter substance must have been produced simultaneously, and some of it may have been washed away, in the form of mud, from the coral reef of Faxoe, and dispersed over the deeper parts of the same ocean, just as the white mud, swept out of the lagoons of the Bermudas or coral islets of the Pacific, must form deposits of white chalk, covering much wider spaces than those occupied by the reefs.

The same remarks apply to a rock, which reposes on the Upper Chalk with flints, at St. Peter's Mount, Maestricht, and at Ciply, near Mons. It is a soft, yellowish stone, not very unlike chalk, and "includes siliceous masses, which are much more rare than those of the chalk, of greater bulk, and not composed of black flint, but of chert and calcedony."* Like the Faxoe stone, it is characterized by a peculiar assemblage of organic remains which are specifically distinct from those of the tertiary period, but many of them common to the white chalk.

As these Maestricht beds have been thought to be intermediate in character between the secondary and tertiary formations, it may be proper to

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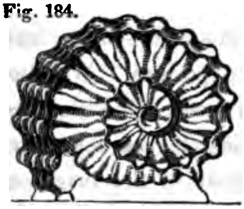
* Fitton, Geol. Proceedings, 1830.

Fig. 184.



Ammonites Rhotomagensis.
Maestricht; found by Count Munster.

mention, as opposed to this opinion, that the *Ammonite* (Fig. 184.), *Baculite*, *Hamite*, and *Hippurite*, have been found in the Maestricht limestone, genera which have not yet been detected in strata newer than the chalk. In the same formation, also, large turtles have been found, and a gigantic reptile, the *Mosasaurus*, or fossil Monitor, some of the vertebræ of which appear also in the English chalk.* The osteological characters of this oviparous quadruped prove it to have been intermediate between the living Monitors and Iguanas; and, from the size of the head, vertebræ, and other bones, it is supposed to have been twenty-four feet in length.

The existence of such turtles and saurians seems to imply some neighbouring land, on the sandy shores of which these creatures may have laid their eggs. But a few small islets in mid-ocean, like Ascension, so much frequented by turtles, may perhaps have afforded the required retreat to these cretaceous reptiles.

Origin of the flint in chalk. — It is difficult to give a satisfactory explanation of the origin of the flint in chalk, whether it occurs in isolated nodules or continuous layers. It seems that there was originally siliceous as well as calcareous earth in the muddy bottom of the cretaceous sea, at least when the upper chalk was deposited. Whether both these earths could have been alike supplied by the decay of organic bodies may be matter of speculation; but what was said of the origin of Tripoli (see p. 53.) shows how microscopic infusoria can give rise to dense masses of pure flint. The skeletons of many living sponges consist of needles or spicula of flint, and these are found very abundantly in the flints of the chalk. There are also other living zoophytes, which have the power of secreting siliceous matters from the waters of the sea, just as mollusca secrete calcareous particles.

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* See Mantell's Geol. of S. E. of England.

From whatever source the mud derived its silex, we may attribute the parallel disposition of the flinty layers to successive deposition. The distances between the layers, says Dr. Buckland, must have been regulated by the intervals of precipitation, each new mass forming at the bottom of the ocean a bed of pulpy fluid, which did not penetrate the preceding bed on which it rested, because the consolidation of this last was so far advanced as to prevent such intermixture.* Nevertheless the separation of the flint into layers, so distinct from the chalk, is a singular phenomenon, and not yet accounted for. Perhaps, as the specific gravity of the siliceous exceeds that of the calcareous particles, the heavier flint may have sunk to the bottom of each stratum of soft mud.

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* Geol. Trans., First Series, vol. iv. p. 420.

Geographical extent of White Chalk. — The area over which the white chalk preserves a nearly homogeneous aspect is so great that geologists have often despaired of finding any analogous deposits of recent date; for chalk is met with in a northwest and southeast direction, from the north of Ireland to the Crimea, a distance of about 1140 geographical miles, and in an opposite direction it extends from the south of Sweden to the south of Bordeaux, a distance of about 840 geographical miles. But we must not conclude that it was ever spread out uniformly over the whole of this vast space, but merely that there were patches of it, of various sizes, throughout this area. Now, if we turn to those regions of the Pacific over which coral reefs are scattered, we find some archipelagoes of lagoon islands, such as that of the Dangerous Archipelago for instance, and that of Radack, with some adjoining groups, which are from 1100 to 1200 miles in length, and 300 or 400 miles broad; and the space to which Flinders proposed to give the name of the Corallian sea is still larger; for it is bounded on the east by the Australian barrier, on the west by New Caledonia, and on the north by the reefs of Louisiade. Although the islands in these spaces may be thinly sown, the mud of the decomposing zoophytes may be scattered far and wide by oceanic currents.

Green-sand formation. — The lower part of the Cretaceous group in England, is divisible, as we have already seen, into Upper Green-sand, Gault, and Lower Green-sand. The green grains have been found, by analysis, to consist chiefly of silicate of iron, and they agree in composition with chlorite. The inferior white marly chalk becomes more and more charged with these grains until it passes into the upper green-sand, a formation of sand and sandy marl, frequently mixed with chert, and this again passes downwards into the clay and marl, provincially called Gault. Both of these subdivisions, although often diminishing in volume to a thickness of two or three yards, form distinct and continuous bands of sand and clay between the chalk and lower green-sand throughout considerable tracts in England, France, and Belgium; and each preserves throughout this space certain mineral peculiarities and characteristic fossils.

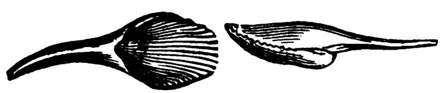
The lower green-sand below the gault is formed partly of green and partly of ferruginous sand and sandstone, with some limestone. These rocks succeed each other in the following descending order in Kent: —

No. 1.	Sand, white, yellowish, or ferruginous, with concretions of limestone and chert	70 feet.
2.	Sand with green matter	70 to 100 feet.
3.	Calcareous stone, called Kentish rag.	60 to 80 feet.*

The fossils of the green-sand are marine, and some of them, like the *Pecten quinquecostatus* (Fig. 186.), range through all the members of the series. Several forms of cephalopoda, such as the *Hamite* (Fig. 187), *Scaphite*, and others, distin-

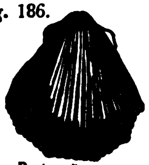
FOSSILS OF THE GREEN-SAND FORMATION.

Fig. 185.



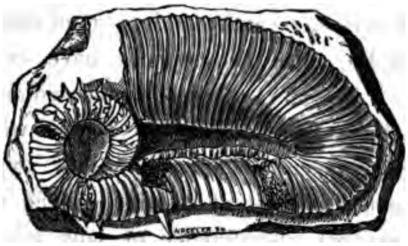
a. *Terebratula lyra.* } Upper green-sand.
b. *Same, seen in profile.* } France.

Fig. 186.



Pecten 5 costatus. Upper and lower green-sand.

Fig. 187.



Hamites spiniger (Fitton); near Folkstone.† Gault.

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* Fitton, Geol. Trans., Second Series, vol. iv. p. 319.

† Ibid. pl. 12.

guish the Green-sand formation in England from the White Chalk.

Origin of the Green-sand formation. — Unlike the white chalk, this deposit consists of a succession of ordinary beds of sand, clay, marl, and impure limestone, the materials of which might result from the wearing down of preëxisting rocks. The nature of these derivative rocks we learn, from finding in the green-sand pebbles of quartz, quartzose sandstone, jasper, and flinty slate, together with grains of chlorite and mica.* But we naturally inquire, how it could happen that, throughout a large submarine area, there should be formed first, a set of mechanical strata, such as the green-sand, and then over the same space a pure zoophytic and shelly limestone, such as the white chalk. Certain causes, which, during the first period, gave rise to deposits of mud, sand, and pebbles, must subsequently have ceased to act; for it is evident that no similar sediment disturbed the clear waters of the sea in which the white chalk accumulated. The only hypothesis which seems capable of explaining such changes is the gradual submergence of land which had been previously exposed to aqueous denudation. This operation may have gone on with such slowness as to allow time for considerable fluctuations in the state of the organic world, so that different sets of strata, beginning with the Lower Green-sand, and ending with the Upper White Chalk, may each contain some peculiar remains of animals which lived successively in the sea; while some species may have continued to exist throughout the whole period, and are therefore common to all these formations.

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* Fitton, Geol. Trans., Second Series, vol. iv. p. 116.

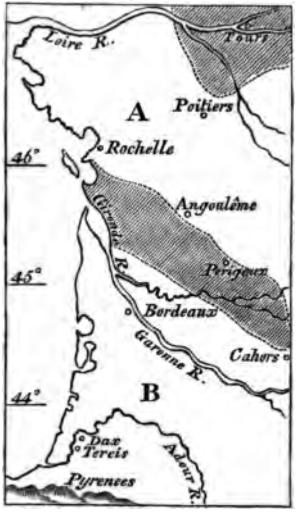
It will be seen in the next chapter, when we treat of the strata called the Wealden, that such a general subsidence of land as is here supposed to explain the manner in which the Chalk succeeds the Green-sand, may be inferred from other independent proofs to have taken place throughout large areas.

It cannot, however, be assumed, that all the green-sand in Europe had ceased to be deposited before any chalk began to accumulate. Such, indeed, was the order of events in parts of England, France, Belgium, and Denmark; but if we compare different countries, and some of these not far distant from each other, we find reason to believe that sand and clay continued to be thrown down in one place, while pure chalk was forming in another. In Westphalia, for example, strata containing the same fossils as the white chalk of England, consist of sand and marl with green grains like the upper green-sand. Similar facts have been observed in Hungary, in the Carpathian mountain chain. Such variations would occur if the supposed sinking down of land did not take place simultaneously everywhere; and for this reason the minor subdivisions of the Cretaceous group, however persistent and uniform in their mineral characters in some regions, vary rapidly, and change entirely in other directions.

Difference between the chalk of the north and south of Europe. — By the aid of the three tests of relative age, namely, superposition, mineral character, and fossils, the geologist has been enabled to refer to the same Cretaceous period certain rocks in the north and south of Europe, which differ greatly, both in their fossil contents and in their mineral composition and structure.

If we attempt to trace the cretaceous deposits from England and France to the countries bordering the Mediterranean, we perceive, in the first place, that the chalk and green-sand in the neighbourhood of London and Paris form one great continuous mass, the strait of Dover being a trifling interruption, a mere valley with chalk cliffs on both sides. We then observe that the main body of the chalk which surrounds Paris stretches from Tours to near Poitiers (see the annexed map, Fig. 188., in which the shaded part represents chalk).

Fig. 188.



Between Poitiers and La Rochelle, the space marked A on the map separates two regions of chalk. This space is occupied by the Oolite and certain other formations older than the chalk, and has been supposed by M. E. de Beaumont to have formed an island in the cretaceous sea. South of this space we again meet with a formation which we at once recognise by its mineral character to be chalk, although there are some places where the rock becomes oolitic. The fossils are, upon the whole, very similar; especially certain species of the genera *Spatangus*, *Ananchytes*, *Cidarites*, *Nucula*, *Ostrea*, *Gryphæa* (*Exogyra*), *Pecten*, *Plagiostoma* (*Lima*), *Trigonia*, *Catillus*, and *Terebratula*.* But *Ammonites*, as M. d'Archiac observes, of which so many species are met with in the chalk of the north of France, are scarcely ever found in the southern region; while the genera *Hamite*, *Tur-*

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* Archiac, sur la Form. Crétacée du S. O. de la France, Mém. de la Soc. Géol. de France, tom. ii.

rilite and *Scaphite*, and perhaps *Belemnite*, are entirely wanting.

On the other hand, certain forms are common in the south which are rare or wholly unknown in the north of France. Among these may be mentioned many *Hippurites*, *Sphærulites*, and other members of that great family of mollusca called *Rudistes* by Lamarck, to which nothing analogous has been discovered in the living creation. Although very uncommon in England, one species of this family has been discovered in our chalk.

Fig. 189.

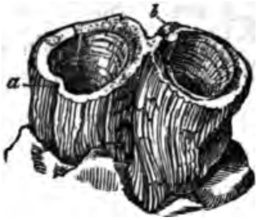


Fig. 190.

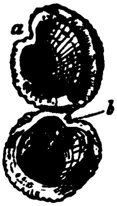


Fig. 191.

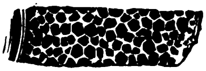
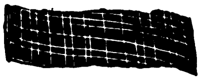


Fig. 192.



Hippurites Mortoni, Mantell. Houghton, Sussex.
Diameter one seventh of nat. size.

Fig. 189. Two individuals deprived of their opercula, adhering together.

190. Same seen from above.

191. Transverse section of part of the wall of the shell, magnified to show the structure.

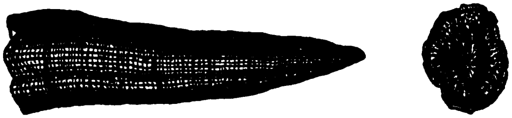
192. Vertical section of the same.

On the side where the shell is thinnest, there is one external furrow and corresponding internal ridge, *a. b.* Figs. 189, 190;

but they are usually less prominent than in these figures. This species has been referred to *Hippurites*, but does not, I believe, fully agree in character with that genus. I have never seen the opercular piece, or *valve*, as it is called by those conchologists who regard the *Rudistes* as bivalve mollusca. The specimen above figured was discovered by Mr. F. Dixon.

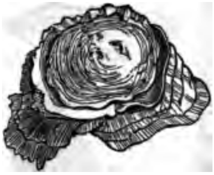
But this family which is so feebly represented in England and the north of France, becomes quite characteristic of rocks of the Cretaceous era in the south of France, Spain, Greece, and other countries bordering the Mediterranean.

a Fig. 193. *b*



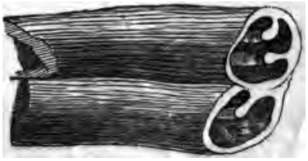
a. Hippurites, Lamk. } Lower chalk, South of France.
b. Opercular valve of *H. radiosa.* }

Fig. 194.



Sphærulites agariciformis.

Fig. 195.

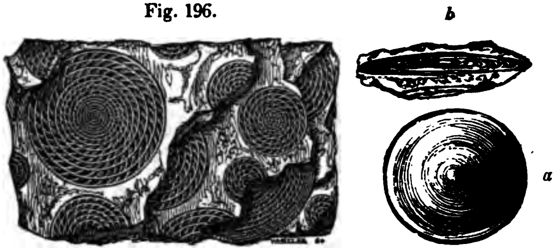


Hippurites organisans, Desm. Pyrenees.

Between the region of chalk last mentioned in which Perigueux is situated, and the Pyrenees, the space B intervenes (see Map).

Here the tertiary strata cover, and for the most part conceal, the cretaceous rocks, except in some spots where they have been laid open by the denudation of the newer formations. In these places they are seen still preserving the form of a white chalky rock, which is charged in part with grains of green sand. Even as far south as Tercis, on the Adour, near Dax, cretaceous rocks retain this character where I examined them in 1828, and where M. Grateloup has found in them ***Ananchytes ovata*** (Fig. 178.), and other fossils of the English chalk, together with ***Hippurites.*** When we arrive at Bayonne and the Pyrenees, the Cretaceous formation, although still exhibiting some of the same mineralogical peculiarities, is nevertheless greatly changed. Its calcareous division consists for the most part of compact crystalline marble, often full of Nummulites (see Fig. 196.), and those

Fig. 196.



Nummulite limestone; Peyrehorade, Pyrenees.
a. External surface of one of the nummulites, of which longitudinal sections are seen in the limestone.
b. Transverse section of same.

portions which may be imagined to represent the green-sand, are composed of shales, grits, and micaceous sandstone, containing impressions of marine plants, together with lignite and coal. There are also beds of red sandstone and conglomerate belonging to the same group. These rocks ascend gradually into the highest parts of the Pyrenees, and cross over into Spain, where the Cretaceous system assumes a character still more unlike that of northern Europe.

Here, as on the north side of the Pyrenees, the most conspicuous fossils are *Hippurites*, *Sphærulites*, and *Nummulites*. The last-named fossil, so called from its resemblance to a piece of money, is a genus of foraminifera very abundant in the tertiary strata of northern Europe; but is rare in the cretaceous system except in the south of Europe.

So many species and genera of shells now wanting in our northern seas, are frequent in the Mediterranean, that we need not be surprised, when following from north to south the deposits of the old cretaceous sea, at finding similar modifications in organic forms.

The cretaceous rocks in the Alps, Italy, Greece, and Asia Minor, are distinct in like manner from the type of that formation in the north of Europe; yet their age in most of these countries can be clearly ascertained, partly by following them continuously from the north in the manner above described; and partly by their position below the tertiary, and above the oolitic strata.

We learn from the researches of M. M. Boblaye and Virlet, that the cretaceous system in the Morea, is composed of compact and lithographic limestones of great thickness; also of granular limestones with jasper; and in some districts, as in Messenia, a puddingstone with a siliceous cement, more than 1600 feet in thickness, belongs to the same group.*

It is evident, observe these geologists, from the great range of the hippurite and nummulite limestone, that the South of Europe was occupied at the Cretaceous period by an immense sea, which extended from the Atlantic Ocean into Asia, and comprehended the southernmost part of France, together with Spain, Sicily, part of Italy, and the Austrian Alps, Dalmatia, Albania, a portion of Syria, the isles of the Ægean, coasts of Thrace, and the Troad.

In proportion, therefore, as we enlarge the sphere of our researches, we may find in the strata of one era, the mineralogical counterparts of the rocks, which, in a single country like England, may characterize successive periods. Thus, the grits, sandstone, and shale with coal, of the Pyrenees have actually been mistaken by skilful miners for the ancient Carboniferous group of England and France. In like manner, the Cretaceous red marl and salt of northern Spain have been regarded as the same as our New Red and saliferous sandstone; and the lithographic limestone of the Morea might be confounded with the Oolite of Solenhofen in Germany.

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* Bull. de la Soc. Géol. de France, tom. iii. p. 149.

The beginner, perhaps, on hearing these facts, may object to the term cretaceous, as applied to the rocks of the southern region in which there is no chalk. But the term green-sand would have been equally inappropriate as a general name for this group; and that of hippurite and nummulite limestone, however well suited to the Mediterranean region, would be inapplicable to the chalk of the north. Scarcely any designation would remain unexceptionable as we enlarge the bounds of our knowledge, and we must therefore be content to retain many ancient names, as simply expressing the mineral or palæontological characters of rocks *in the country where they were first studied.*

CHAPTER XVIII.

WEALDEN GROUP.

The Wealden, including the Weald clay, Hastings sand, and Purbeck beds — Intercalated between two marine formations — Fossil shells freshwater, with a few marine — Cypris — Fish — Reptiles — Birds — Plants — Section showing passage of Wealden beneath chalk — Junction of Wealden and Oolite — Dirt-bed — Theory of gradual subsidence — Proofs that the Wealden strata, notwithstanding their thickness, may have been formed in shallow water — Geographical extent of Wealden — Bray near Beauvais — Relation of the Wealden to the Lower Green Sand and Oolite.

BENEATH the cretaceous rocks in the S. E. of England, a freshwater formation is found called the Wealden, which, although it occupies a small area in Europe, as compared to the chalk, is nevertheless of great interest, as being intercalated between two marine formations. It is composed of three minor groups, of which the aggregate thickness in some places cannot be less than 800 feet.* These subdivisions are,

		Thickness.
1st.	Weald Clay, sometimes including thin beds of sand and shelly limestone - -	140 to 280 ft.
2d.	Hastings sand, in which occurs some clays and calcareous grits; — between -	400 and 500 ft.
3d.	Purbeck beds, consisting of various kinds of limestones and marls - - -	about 250 ft.

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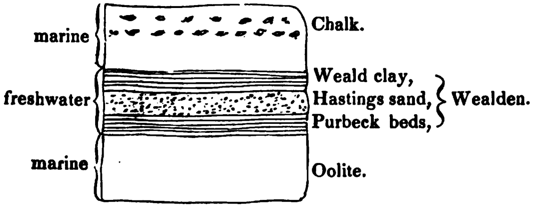
* Dr. Fitton, Geol. Trans. vol. iv. p. 320. Second Series.

To all these subdivisions, the common name of the Wealden has been given, because they may be best studied in part of Kent, Surrey, and Sussex, called the Weald.

We have seen that the fossils of the Chalk and Green-Sands which repose upon the Wealden are all marine, and the species numerous; and the same remark applies to the Portland stone and other members of the Oolitic series which lie immediately beneath (see Fig. 197.). But in the Wealden itself, although the fossils are abundant as to quantity, the number of different species is comparatively small, and by far the greater part of them show that they were deposited in a freshwater lake, or estuary communicating with the sea.*

Fig. 197.



Position of the Wealden between two marine formations.

Fossils of the Wealden. — The shells of this formation are almost exclusively of fluviatile or lacustrine genera, such as *Melanopsis*, *Paludina*, *Neritina*, *Cyclas*, *Unio*, and others. The individuals are sometimes in such profusion, that the surface of each thin layer of marl or clay is covered with the valves of *Cyclas*, and whole beds of limestone are almost entirely composed of *Paludinæ*. Intermixed with these freshwater shells, there are a few which seem to mark the occasional presence of salt water, as for example, a species of *Bulla*, together with an Oyster, and the *Exogyra*, a genus of unimuscular bivalves allied to the oyster (see Fig. 198.). The conclusion to be drawn from the presence of a *Corbula* (see Fig. 199.) and *Mytilus* is more doubtful; for although these genera are for the most part marine, still there is a *Mytilus* living in the Danube, and one species of *Corbula* inhabits the river La Plata, in South America, as well as the adjoining sea, while another is common to the Caspian, and the rivers

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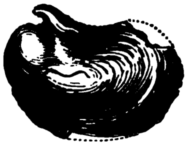
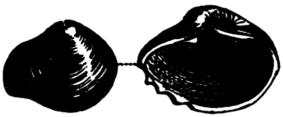
* Fitton, Geol. Trans. vol. iv. p. 104. Second Series.

Fig. 198.



Exogyra bulla, Fitton.

Fig. 199.

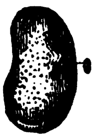


Corbula, alata, Fitton.
Magnified.

Don and Wolga. But admitting all these to have been marine, they by no means outweigh the evidence, both of a positive and negative kind, derived from shells in favor of the freshwater origin of the Wealden. In no part of this deposit do we meet with ammonites, belemnites, terebratulæ, corals, sea-urchins, or other testacea and zoophytes so characteristic of the chalk above, or the oolite below, the Wealden.

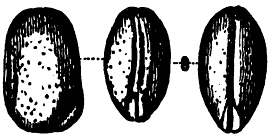
Shells of the *Cypris*, an animal allied to the Crustacea, and before mentioned (p. 67.) as abounding in lakes and ponds, are also plentifully scattered through the clays of the Wealden, sometimes producing, like plates of mica, a thin lamination (see Fig. 203.). Similar cypriferous marls are found in the lacustrine tertiary beds of Auvergne, and in recent deposits of shell-marl.

Fig. 200.



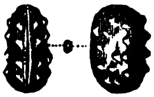
Cypris spinigera, Fitton.

Fig. 201.



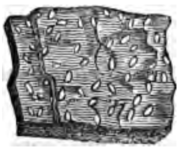
Cypris Valdensis, Fitton. (*C. faba,* Min. Con. 485.)

Fig. 202.



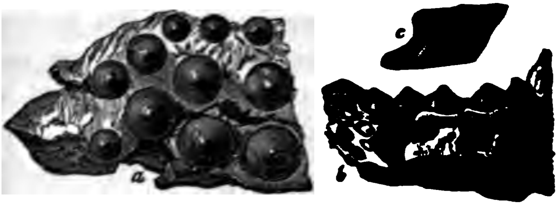
Cypris tuberculata, Fitton.

Fig. 203.



The fishes of the Wealden belong partly to the genera *Pycnodus* and *Hybodus* (see Figures in Chapters 21 and 22.), forms common to the Wealden and Oolite; but the teeth and scales of a species of *Lepidotus* are most widely diffused (see

Fig. 204.



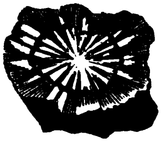
Lepidotus Mantelli, Agass. Wealden.
a. palate and teeth. *b.* side view of teeth. *c.* scale.

Fig. 204.). The general form of these fish was that of the carp tribe, although perfectly distinct in anatomical character, and more allied to the pike. The whole body was covered with large rhomboidal scales, very thick, and having the exposed part covered with enamel. Most of the species of this genus are supposed to have been either river fish, or inhabitants of the coasts, having not sufficient powers of swimming to advance into the deep sea.

Among the remains of vertebrata, those of reptiles form the most remarkable feature. Some of them belong to tortoises, such as the *Trionyx* and *Emys*, genera now occurring in freshwater in tropical regions. Of Saurian lizards there are at least five genera; the Crocodile, Plesiosaur, Megalosaur, Iguanodon, and Hylæsaur. The Iguanodon, of which the remains were first discovered by Mr. Mantell, was an herbivorous reptile, and was regarded by Cuvier as more extraordinary than any with which he was acquainted; for the teeth, though bearing a great analogy to the modern Iguanas which now frequent the tropical woods of America and the West Indies, exhibit many striking and important differences (see Fig. 206.). It appears that they have been worn by mastication; whereas the existing herbivorous reptiles clip and gnaw off the vegetable productions on which they feed, but do not chew them. Their teeth, when worn, present an appearance of having been chipped off, and never, like the fossil teeth of the Iguanodon, have a flat ground surface (see Fig. 205.), resembling the grinders of herbivorous mammalia. Mr. Mantell computes that the teeth and bones of this animal

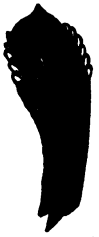
Teeth of Iguanodon.

Fig. 205.



Crown of tooth in adult, worn down.
Mantell.

Fig. 206.



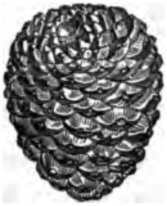
Pointed tooth of a young animal.
Mantell.

which have passed under his examination during the last twenty years, must have belonged to no less than seventy-one distinct individuals; varying in age and magnitude from the reptile just burst from the egg, to one of which the femur measured twenty-four inches in circumference. Yet notwithstanding that the teeth were more numerous than any other bones, it is remarkable that it was not till the relics of all these individuals had been found, that a solitary example of part of a jawbone was obtained.

The bones of birds of the order *Grallæ* or waders have been discovered by Mr. Mantell in the Wealden, and appear to be the oldest well-authenticated examples of fossils of this class hitherto found in Great Britain.* But no portion of the skeleton of a mammiferous quadruped has yet been met with.

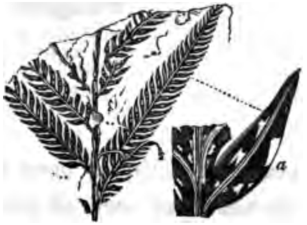
The vegetable remains, which are numerous,

Fig. 207.



Cone from the Isle of Purbeck, resembling the Dammara of the Moluccas. Fitton.

Fig. 208.



Sphenopteris gracilis (Fitton), *from near Tunbridge Wells.*
a. portion of the same magnified.

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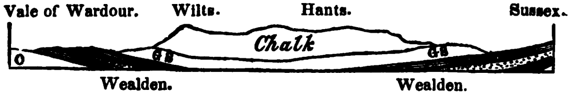
* Mantell, Proceedings Geol. Soc. vol. ii. p. 203.

exhibit many characters of a tropical flora, some being allied to the living genera *Cycas* and *Zamia* (see Fig. 211.), others to large *Equiseta*. There are also *Coniferæ* allied to *Araucaria*, and other genera of warm climates (see Fig. 207.), besides numerous ferns (see Fig. 208.).

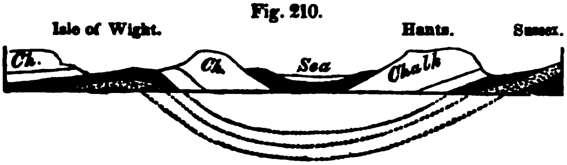
Passage of Wealden beneath Chalk.— It has been already seen that the chalk and green-sand have an aggregate thickness of 1000 or sometimes 1500 feet. It is therefore a wonderful fact that after penetrating these rocks, we come down upon a subjacent *freshwater* formation from 800 to 1000 feet in thickness. The order of superposition is clear, for we see the Weald Clay passing beneath the Green-Sand in various parts of Surrey, Kent, and Sussex; and if we proceed from Sussex westward to the Vale of Wardour, we there again observe the same formation occupying the same relative position, and resting on the Oolite (see Fig. 209.). Or if we pass from the base of the south downs in Sussex, and cross to the Isle of Wight, we there again meet with the same series reappearing beneath the Green-Sand, and we cannot doubt that the beds are prolonged sub-

Fig. 209.



terraneously, as indicated by the dotted lines in Fig. 210.

Fig. 210.



It has been already suggested that, during the accumulation of the Green-Sand, there was a gradual sinking down and submersion of land, by which the wide open sea of the Chalk was produced. But the position of the Wealden points still more forcibly to such a conclusion, and especially the appearances exhibited at the point of junction of the Wealden, and the Oolitic formation on which it rests. First, in regard to its junction with the superincumbent Lower Green-Sand, the beds of this last, says Dr. Fitton, repose in the southeast of England, conformably upon those of the subjacent Weald Clay. There is no indication of disturbance: "To all appearance the change from the deposition of the freshwater remains to that of the marine shells, may have been effected simply by a tranquil submersion of the land to a greater depth beneath the surface of the waters." *

Portland dirt-bed and proofs of subsidence.—But when we examine the contact of the Purbeck beds, or *inferior* division of the Wealden, with the Portland stone, or upper member of the Oolite, some very singular phenomena are observed. Between the two formations, the marine and the freshwater, there intervenes in Portland a layer of dark matter, called by the quarrymen the "Dirt," or "Black dirt," which appears evidently to have been an ancient vegetable soil. It is from twelve to eighteen inches thick, is of a dark brown or black color, and contains a large proportion of earthy lignite. Through it are dispersed rounded fragments of stone, from three to nine inches in diameter, in such numbers that it almost deserves the name of gravel. Many silicified trunks of coniferous trees, and the remains of plants allied to the *Zamia* and *Cycas* are buried in this dirt-bed (see figure of living *Zamia*).

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* Geol. of Hastings, p. 28.

These plants must have become fossil on the spots where they grew. The stumps of the trees stand erect for a height of from one to three feet, and even in one instance to six feet, with their roots attached to the soil at about the same distances from one another as the trees in a modern forest.* The carbonaceous matter is most abun-

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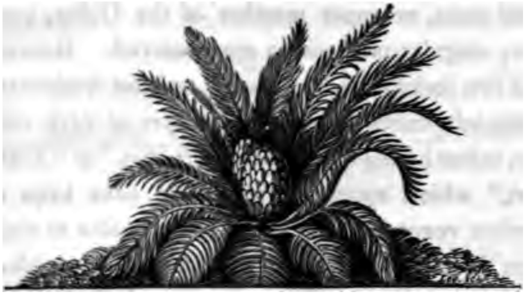
* Mr. Webster first noticed the erect position of the trees and described the Dirt-bed. The account here given is drawn from Dr. Buckland and Mr. De la Beche, Geol. Trans., Second Series, vol. iv. p. 1.; Mantell, Geol. of S. E. of England, p. 336.; and Dr. Fitton, Geol. Trans., Second Series, vol. iv. p. 220.

Fig. 211.



Zamia spiralis; Southern Australia.*

dant immediately around the stumps, and round the remains of fossil *Cycadeæ*.†

Besides the upright stumps above mentioned, the dirt-bed contains the stems of silicified trees laid prostrate. These are partly sunk into the black earth, and partly enveloped by a calcareo-siliceous slate which covers the dirt-bed. The fragments of the prostrate trees are rarely more than three or four feet in length; but by joining many of them together, trunks have been restored having a length from the root to the branches of from 20 to 23 feet, the stems being undivided for 17 or 20 feet and then forked. The diameter of these near the roots is about one foot.‡ Root-shaped cavities were observed by Professor Henslow to descend from the bottom of the dirt-bed into the subjacent Portland stone, so that the uppermost beds of the Portland limestone, though now solid, were in a soft and penetrable state when the trees grew.*

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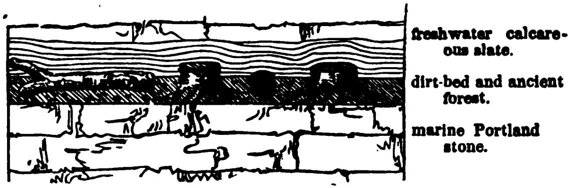
* See Flinder's Voyage.

† Fitton, Geol. Trans., Second Series, vol. iv. pp. 220, 221.

‡ Fitton, ibid.

The thin layers of calcareous slate (Fig. 212.), were evidently deposited tranquilly, and would have been horizontal but for the protrusion of the stumps of the trees, around the top of each of which they form hemispherical concretions.

Fig. 212.



Section in Isle of Portland, Dorset. (Buckland and De la Beche.)

The dirt-bed is by no means confined to the island of Portland, but is seen in the same relative position in a cliff east of Lulworth Cove, in Dorsetshire, where, as the strata have been disturbed, and are now inclined at an angle of 45°, the stumps of the trees are also inclined at the same angle in an opposite direction, — a beautiful illustration of a change in the position of beds originally horizontal

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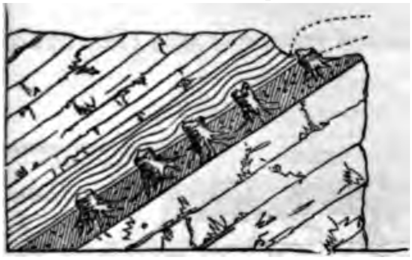
* Buckland and De la Beche, Geol. Trans., Second Series, vol. iv. p. 16.

(see Fig. 213.). Traces of the dirt-bed have also been observed by Dr. Buckland, about two miles north of Thame, in Oxfordshire; and by Dr. Fitton, in the cliffs of the Boulonnois, on the French coast; but, as might be expected, this freshwater deposit is of limited extent when compared to most marine formations.

Fig. 213.


freshwater calcareous slate.
dirt-bed.
Portland stone of marine formation.

Section in Cliff east of Lulworth Cove. (Buckland and De la Beche.)

From the facts above described, we may infer, first, that the superior beds of the Oolite, which are full of marine shells, became dry land, and covered by a forest, throughout a portion of the space now occupied by the south of England, the climate being such as to admit the growth of the *zamia* and *cycas*. 2dly. This land at length sank down and was submerged with its forests beneath a body of freshwater, from which sediment enveloping fluviatile shells was deposited. 3dly. "The regular and uniform preservation of this thin bed of black earth over a distance of many miles, shows that the change from dry land to the state of a freshwater lake or estuary, was not accompanied by any violent denudation, or rush of water, since the loose black earth, together with the trees which lay prostrate on its surface, must inevitably have been swept away, had any such violent catastrophe then taken place." *

The dirt-bed has been described above in its most simple form, but in some sections the appearances are more complicated. The forest of the dirt-bed was not everywhere the first vegetation which grew in this region. Two other beds of carbonaceous clay, one of them containing *Cycadeæ* in an upright position, have been found below it,† which implies other oscillations in the level of the same ground, and its alternate occupation by land and water more than once. There must have been, first, the sea in which the corals and shells of the Oolite grew; then, land, which supported a vegetable soil with *Cycadeæ*; then, a lake or estuary, in which freshwater strata were deposited; then, again, land, on which other *Cycadeæ* and a forest of dicotyledonous trees flourished: then, a second submergence under freshwater, in which the Wealden strata were gradually formed; and, finally, in the cretaceous period, a return over the same space of the ocean.

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* Buckland and De la Beche, Geol. Trans., Second Series, vol. iv. p. 16.

† Fitton, Geol. Trans., Second Series, vol. iv. p. 223.

To imagine such a series of events will appear extravagant and visionary to some who are not aware that similar changes occur in the ordinary course of nature; and that large areas near the sea are now subject to be laid dry, and then submerged, after remaining for years covered with houses and trees.*

In some of these modern revolutions, such as have been witnessed in the delta of the Indus, in Cutch, we have instances of land being permanently laid under the waters, both of the river and the sea, without the soil and its shrubs being swept away; but such preservation of an ancient soil must be a rare exception to the general rule, for it would be destroyed by denuding waves and currents, unless the land sank suddenly down to a great depth, or unless its form was such as to exclude the free ingress of the sea.

Notwithstanding the enormous thickness of the Wealden, exceeding in some places perhaps 1000 feet, there are many grounds for believing that the whole of it was a deposit in water of a moderate depth, and often extremely shallow. This idea may seem startling at first, yet such would be the natural consequence of a gradual and continuous sinking of the ground in an estuary or bay, into which a great river discharged its turbid waters. By each foot of subsidence, the fundamental rock, such as the Portland Oolite, would be depressed one foot further from the surface of the ocean; but the bay would not be deepened, if new strata of mud and sand should raise the bottom one foot. On the contrary, such sand and mud might be frequently laid dry at low water, or overgrown for a season by a vegetation proper to marshes. At different heights in the Hastings Sand, in the middle of the Wealden, we find again and again slabs of sandstone with a strong ripple-mark, and between these slabs beds of clay, many yards thick. In some places, as at Stammerham, near Horsham, there are indications of this clay

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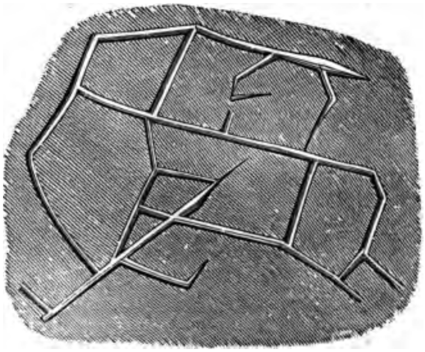
* For an account of recent movements of land attended by such consequences, see Principles of Geology, Index, "Cutch," "Sindree," &c.

Fig. 214.



Underside of slab of sandstone about one yard in diameter; Stammerham, Sussex.

having been exposed so as to dry and crack before the next layer was thrown down upon it. The open cracks in the clay have served as moulds, of which casts have been taken in relief, and which are, therefore, seen on the lower surface of the sandstone * (see Fig. 214.).

Near the same place a reddish sandstone occurs in which are innumerable traces of a fossil vegetable, apparently *Sphenopteris*, the stems and branches of which are disposed as if the plants were standing erect on the spot where they originally grew, the sand having been gently deposited upon and around them; and similar appearances have been remarked in other places in this formation.† In the same division also of the Wealden, at Cuckfield, is a bed of gravel or conglomerate, consisting of water-worn pebbles of quartz and jasper, with rolled bones of reptiles. These must have been drifted by a current, probably in water of no great depth.

The occasional presence of oysters in the Purbeck limestone, and throughout the Hastings sand and Weald clay, proves that the waters of the sea sometimes found access into the estuary ‡, whether in consequence of subsidence, or in seasons when the body of freshwater was lessened in volume.

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* Observed by Mr. Mantell and myself in 1831.

† Mantell, Geol. of S. E. of England, p. 244.

‡ Fitton, Geol. Trans, 2d Ser., vol. iv. p. 321.

Geographical extent. — The Wealden strata have been traced about 200 English miles from west to east, from Lulworth Cove to near Boulogne, in France, and about 220 miles from northwest to southeast, from Whitchurch, in Buckinghamshire, to Beauvais, in France. If the formation be continuous throughout this space, which is very doubtful, it does not follow that the whole was contemporaneous; because in all likelihood the physical geography of the region underwent frequent change throughout the whole period, and the estuary may have altered its form, and even shifted its place. Yet some modern deltas are of vast size, as for example that of the newly-discovered Quorra, or Niger, in Africa, which stretches into the interior for more than 170 miles, and occupies, it is supposed, a space of more than 300 miles along the coast; thus forming a surface of more than 25,000 square miles, or equal to about one half of England.*

I have stated that the Wealden has been observed near Beauvais, in France; and the locality is marked in the section at p. 387. It is called "the country of Bray;" and resembles in structure the English Weald between the North and South Downs. In a similar manner the Green-Sand crops out from beneath the Chalk, and freshwater strata from beneath the Green-Sand. One member of the series, a fine whitish sand, contains impressions of ferns, considered by M. Adolphe Brongniart as identical with *Lonchopteris Mantelli*, a plant found frequently in the Wealden. I examined part of the valley of Bray in company with M. Graves, in 1833, and I observed that the sand last mentioned, with its vegetable remains, was intercalated between two sets of marine strata, containing *trigoniæ*, and referred by French geologists to the lower Green-Sand. In the same country of Bray, and associated with the same formation, is a limestone resembling the Purbeck marble, and containing a *Paludina* which seems specifically identical with that of Purbeck.

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* Fitton, Geol. of Hastings, p. 58.; who cites Lander's Travels.

If it be asked where the continent was placed from the ruins of which the Wealden strata were derived, and by the drainage of which a great river was fed, we are half tempted to speculate on the former existence of the Atlantis of Plato. The story of the submergence of an ancient continent, however fabulous in history, may be true as a geological event. Its disappearance may have been gradual; and we need not suppose that the rate of subsidence was hastened at the period when the displacement of a great body of freshwater by the Cretaceous sea took place. Suppose the mean height of the land drained by the river of the Wealden estuary to have been no more than 800 or 1000 feet; in that case, all except the tops of the mountains would be covered as soon as the fundamental Oolite and the dirt-bed were sunk down about 1000 feet below the level which they occupied when the forest before mentioned was growing. Towards the close of the period of this subsidence, both the sea would encroach and the river diminish in volume more rapidly; yet in such a manner, that we may easily conceive the sediment at first washed into the advancing sea to have resembled that previously deposited by the river in the estuary. In fact, the upper beds of the Wealden, and the inferior strata of the Lower Green-Sand, are not only conformable, but of similar mineral composition.

It is also a remarkable fact, that the same *Iguanodon Mantelli* which is so conspicuous a fossil in the Wealden, has recently been discovered near Maidstone, in the overlying Kentish rag, or marine limestone of the Lower Green-Sand. Hence we may infer that some of the saurians which inhabited the country of the great river, continued to live when part of the country had become submerged beneath the sea. Thus, in our own times, we may suppose the bones of large alligators to be frequently entombed in recent freshwater strata in the delta of the Ganges. But if part of that delta should sink down so as to be covered by the sea, marine formations might begin to accumulate in the same space where freshwater beds had previously been formed; and yet the Ganges might still pour down its turbid waters in the same direction, and carry the carcasses of the name species of alligator to the sea, in which case their bones might be included in marine as well as in subjacent freshwater strata.

Age of the Wealden. — Some geologists have classed the Wealden as a member of the Cretaceous group, while others have considered it as more nearly connected with the antecedent Oolitic deposits; nor is it easy to decide which opinion is preferable, because the organic remains of the Cretaceous and Oolitic groups are marine, while those of the interposed Wealden are almost all freshwater. The testacea and plants of the latter appear as yet to be specifically distinct from those of any other formation; but if we examine the reptiles, it appears that the *Megalosaurus Bucklandi* is common to the Oolite and Wealden, the teeth and bones of this great saurian occurring both in the limestone of Stonesfield and in the Hastings sand.

There are also some *generic* forms, both of reptiles and fish, common to the Oolite and Wealden, and not yet discovered in the Chalk. Vertebræ, for example, of the *Plesiosaurus* are not confined to the Oolite and Lias, but have been also found in the Wealden; and the *Lepidotus*, a genus of fish very characteristic of the Wealden, is unknown in the Cretaceous group, while it is abundant in the Oolitic series.

On the other hand, the same species of Iguanodon has been already mentioned as decidedly common to the Wealden and Green-Sand.

In Scotland, and in different parts of the Continent, marine deposits have been found which are supposed to have been coeval with the Wealden, and which are intermediate in fossil characters as in position between the Cretaceous and Oolitic systems.* They may have been contemporaneous deltas of other rivers flowing from the same ancient continent.

Absence of mammalia. — Among the numerous fossils of the Wealden, no remains of mammalia have been hitherto detected; whereas we should naturally expect, on examining the deposits recently formed at the mouths of the Quorra, Indus, or Ganges, to find, not only the bones of birds and of amphibious and land reptiles, but also those of such warm-blooded quadrupeds as frequent the banks of rivers, or, like the hippopotamus, inhabit their waters. Would not the same current of water which drifted down and rolled the bones of the lizards, tortoises, and fish of the

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* See Fitton, Geol. Trans., Second Series, vol. iv. p. 328., and his references.

Wealden, have also swept down into the de[illegible] some fragments at least of mammiferous bon[illegible] had any animals of the highest class been the[illegible] in existence? As a general rule, indeed, we cannot lay much stress on mere negative evidence; and, as we have seen, although so many teeth of the Iguanodon have been collected, it is only of late that a single small portion of a jaw of one of these gigantic lizards was obtained. Perhaps, in like manner, some bone or tooth of a land quadruped will one day be found. We may at least say, that we have at present no example of a continent covered with a luxurious vegetation, and densely inhabited by large saurians, both aquatic and terrestrial, and by birds, yet at the same time entirely destitute of warm-blooded quadrupeds. The nearest analogy to this state of things is that of New Zealand; and this fact will be more particularly alluded to in the sequel. See Chap. XXV.

In conclusion I may remark, that from the time of the commencement of the Wealden, to far on in the Cretaceous period, we have signs of subsidence, and consequent diminution of land. But after the chalk was formed, or during the tertiary periods, we have, on the contrary, proofs of an increase of land in Europe. But we must not extend these generalizations to the whole surface

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Wealden, have also swept down into the delta some fragments at least of mammiferous bones, had any animals of the highest class been then in existence? As a general rule, indeed, we cannot lay much stress on mere negative evidence; and, as we have seen, although so many teeth of the Iguanodon have been collected, it is only of late that a single small portion of a jaw of one of these gigantic lizards was obtained. Perhaps, in like manner, some bone or tooth of a fossil quadruped will one day be found. We may at least say, that we have at present no example of a continent covered with a luxurious vegetation, and forests inhabited by large saurians, both aquatic and terrestrial, and by birds, yet at the same time entirely destitute of warm-blooded quadrupeds. The nearest analogy to this state of things is that of New Zealand; and this fact will be more particularly alluded to in the sequel. (See Chap. XXIV.)

In conclusion I may remark, that from the time of the commencement of the Wealden, to far on in the Cretaceous period, we have signs of subsidence, and consequent diminution of land. But after the chalk was formed, or during the tertiary periods, we have, on the contrary, proofs of an increase of land in Europe. But we must not extend these generalizations to the whole surface of the globe; for other large areas may have been growing more and more continental during the cretaceous, and more and more oceanic during the tertiary periods, the direction of the prevailing subterranean movement being reversed.

END OF THE FIRST VOLUME.